METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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Marketing Aluminium

FOR several years the exigencies of war necessitated that practically the whole of available supplies of aluminium in this country should be applied to war purposes. So great was the demand during these years that production of primary metal was not only increased but it was necessary further to increase available stocks by the re-use of scrap in the form of secondary aluminium, which was prepared under controlled conditions and placed on a sound and reliable basis. With the removal of restrictions on the uses of this metal and its alloys it is natural that considerable attention is now being directed to its peace-time applications. Large quantities of aluminium are now available and, since the number of people skilled in the working of aluminium far exceeds those available in pre-war days, there should be no difficulty in reopening the channels through which the metal contributed to industrial and household needs before the war. Indeed, there is no reason why peace-time uses for the metal should not be greatly augmented. It will be of interest, therefore, to review briefly some of the former and suggested uses of aluminium and its alloys.

Manufactured articles which are fully processed and ready for use are classified as finished goods. The term generally applies to fabricated wares for sale to the public. Some finished aluminium products are employed mainly as parts for assembly. Others are used for various purposes by manufacturers in many branches of industry and not by personal consumers.

Finished aluminium goods are made by numerous companies in addition to the primary metal producers. An idea of the possibilities associated with the manufacture of these products may be gained from consideration of the different articles mentioned below. Aluminium wares are sold to the public through retail stores, and finished goods for use by manufacturing companies are marketed directly by the producers and also through agents. The Aluminium Exhibition, originally staged at Messrs. Selfridges, in London, last year, and now at Messrs. Lewis, Manchester, indicates the wide variety of applications of this metal.

The largest quantity of aluminium for a single use under peace-time conditions is consumed in the manufacture of cooking utensils and related wares. Probably about 15% of the output of primary metal is employed on the average in normal times for these goods. An inordinate variety of cooking utensils, especially for the household, is marketed and it is noteworthy that a large variety is now available. The more common kinds are pots and pans, double boilers, tea kettles, coffee percolators and several sorts of cookers. Large utensils and special cooking equipment are made particularly for the kitchens of restaurants, ships and hospitals. Also, small and individual wares will soon be available for campers, and light mess kits made for soldiers are now familiar as part of American soldiers' equipment. Aluminium goods often classed with cooking utensils and manufactured generally by the same interests include food trays, thermos bottles, tableware (plates, cups, spoons, etc.), pitchers, beer tankards, flasks and picnic jugs. Wrought utensils are made by drawing or spinning sheet material or by a combination of these processes; quite a number recently marketed are pressings. Cast utensils are produced by sand, and die casting.

Numerous articles made of aluminium can be usefully employed in the home or by the individual. Among household wares may be mentioned lighting fixtures and lamps, desk sets, bowls, vases, trays and sundry artistic or ornamental articles. Among small items for personal use are included combs, hair pins and curlers, collar buttons, belt buckles, match boxes, cigar and cigarette cases, book markers and napkin rings. These goods are made mostly by speciality companies.

Among miscellaneous finished articles for which aluminium or alloys may be employed are buttons, insignia, identifying letters and numerals (for example, house numbers), tax and other tokens, coins of small value, name plates, street signs and markers, phonograph records and statues.

The application of aluminium alloys for the manufacture of furniture is an interesting development in progress for a few years prior to the war and which may well prove a boon in these days of wood scarcity. Wrought and heat-treatable alloys are used, and the construction is by welding. The members are formed from sheet or are seamless tube shapes. Chairs made up most of the output before the war, but increasing numbers of desks, tables, sideboards and other pieces are now being produced. Beds and cots are also made. Chairs have been installed extensively in offices, hotel and other restaurants, railway carriages, ballrooms, bars, airplanes and ships. Also, lockers have been installed on shipboard. An aluminium chair weighs only about half as much as a similar wooden chair.

Many kinds of aluminium containers are made for packing and transporting a multiplicity of products. The following list of applications serves to indicate the scope of the market for containers: Beer barrels, bottles for essential oils and other liquids, boxes for pills and cosmetics, cans for food (in place of tinned steel cans), drums for concentrated acetic acid, vessels for petrol and oil as well as various chemical products, and cases for naval shells. The consumption of aluminium cans by the fish-packing industry had increased rapidly just before the war and offers considerable scope to-day. Such cans may also be employed for packing jam, meat and some other food products. With reference to containers in general it is noteworthy that millions of aluminium closures and seals were produced daily in the several leading industrial countries before war-time

restrictions were imposed. These closures were for bottles and jars to hold liquor, food, milk, soft drinks, cosmetics and drugs. Large containers were also in use, for example, aluminium tanks mounted on railway cars or motor trucks for the transport of concentrated acetic acid, milk and some other liquids. Large quantities of foil were used before the war in the packaging of foodstuffs; its use in chocolate wrapping was quite common. Undoubtedly, these uses for aluminium will again develop rapidly.

Aluminium is applied considerably in the construction of equipment for the chemical process industries. Representative kinds of such equipment include storage tanks, stills, heating coils, stirrers, vats, vessels, receptacles, kettles, condensers, retorts and crystallisers. Some of the products made or handled in aluminium equipment include foods, fruit juices, sugar, candy, milk, nitric acid, certain organic materials, soap, rubber and varnish. Steam jacketed aluminium kettles are used for cooking in canning factories, and much aluminium apparatus is employed in the dairy industry (particularly in Denmark). Other applications are for storage tanks and fermentation vats (aluminium-lined concrete) in brewing, pitch-collection cups in the rosin and turpentine industry, scoops and pails for various purposes.

Many articles of camping gear and for sports use will again be made of aluminium alloys. Among these are ski-sticks, sleighs and toboggans, frames for ice skates, fishing rods and reels, canoes, tent poles, and frames of tennis rackets.

Rivets, nuts, bolts, screws and nails are supplied as finished products for use in the assembly of aluminium structures. Rivets are made of substantially pure aluminium and also of several alloys, and the other products are ordinarily made of alloys. The sizes of rivets are from about $\frac{1}{16}$ to $1\frac{1}{4}$ in. in diameter and of suitable lengths. Different heads are provided for various requirements. Rivets are used for fastening handles to cooking utensils and in the assembly of aircraft, shipping containers and other equipment or structures. Automobile brake linings may be attached to the drums by tubular or semi-tubular rivets. Several kinds of nails are made of heat-treated alloys. These nails are in the same sizes as steel nails and also of greater diameters in order to increase the strength and stiffness. In addition to bolts, nuts and screws, vast numbers of small parts are produced on automatic screw machines.

No discussion of the market for aluminium would be complete without reference to its manifold possibilities in architecture. The employment of aluminium in building was growing rapidly during the decade immediately before the war, and many interesting applications had been made for both exterior construction and inside finish. In construction, aluminium was employed mostly for large office and public buildings, but it is now being used for dwelling houses and other structures. Elsewhere in this issue, Mr. Mortimer discusses this aspect. Both cast and wrought parts are utilised in building for structural and ornamental purposes. The variety of applications is indicated by the following list: Doors, jambs, window frames, grilles, ventilators, spandrels, mullions, cornices, pilasters, finials, railings, corrugated sheets for roofs and siding, shingles, roofing accessories (eaves, gutters, flashings and downspouts), panels, elevator cages, flag poles, etc. Aluminium members have been much favoured for constructing the fronts and display windows of retail shops.

No attempt is made to detail applications in the transport, electrical and other important industries. In subsequent issues it is proposed to consider each under its own heading; it suffices here to state that aluminium is employed in one form or another by a great variety of industries, and the number of separate applications was in excess of 2,000. How soon this diversity of applications will again be reached and surpassed will depend on the speed manufacturers can produce and market the goods or fitments. That there is likely to be a quick sale is indicated by the rapid disposal of aluminium goods recently manufactured for retail.

Some miscellaneous uses not already mentioned include the following: Mine skips and cages, miners' lamps, small boats, lifeboats, bulkheads for flood protection, insect screens, small arms ammunition shells, ice-cube trays, stove construction, radio aerial masts, cages for animals, umbrella frames, fruit juice extractors, street lighting luminaries and light standards, travelling cranes, power-shovel buckets and dragline excavator booms. This short list indicates further the diversified market for aluminium products.

New Metallurgical Society in the West Riding

ALTHOUGH Leeds is a busy industrial city and the centre of numerous factories using and treating metals, until recently no local association existed to further scientific progress in Metal Technology. At the beginning of November, steps were taken to call together a private meeting of industrialists with the object of establishing one. From their discussions it was clear that it would receive wide support and it was therefore decided to call a public meeting in the University on the evening of Monday, December 3, 1945.

Amidst great enthusiasm, the meeting, under chairmanship of Mr. W. R. Berry, M.Sc., of Messrs. Jonas Woodhead and Co. Ltd., Leeds, proceeded to inaugurate the new society, electing the following officers:—Vice-Presidents, Messrs. A. Preece and W. R. Berry; Treasurer, Mr. Douglas Catton; Secretary, Dr. D. R. Hudson; Committee, Dr. M. L. Becker (Huddersfield), Mr. R. E. Campbell, Mr. G. W. Green, Mr. F. K. Neath, Mr. H. W. Ward, Mr. J. Wilkinson.

Major G. H. Kitson was invited to become President, and graciously accepted.

The Inaugural Lecture was delivered by Professor J. H. Andrew of Sheffield University on January 24, 1946, in the spacious lecture theatre "A" of the Chemistry Department of the University. Great interest was aroused by his subject "Metallurgy of the Future" and a vigorous discussion followed.

The next meeting will be held on February 21, 1946, at 7 p.m. in Chemistry Lecture Theatre "B" of Leeds University at which Professor F. C. Thompson of Manchester University will give an address on "Isothermal Changes in Metals." This will deal with theory underlying modern heat-treatment and the use of metal baths in quenching both ferrous and non-ferrous alloys. Special reference will be made to isothermal changes in steel.

Visitors are welcome at the meetings without formal introduction or ticket, but may make themselves known to the Secretary if they wish to do so. Those who can contribute to the discussion will be especially welcome.

Developments in Production Forging

By E. Simister, B.Sc., Ph.D.

(Metallurgical Department, Kirkstall Forge Ltd., Leeds.)

When properly applied mechanical work multiplies the strength of metals and alloys, capable of being forged, due to refinement in the crystalline structure and the development of directional properties in the forged material. These superior mechanical properties of forgings have led to enormously increased demand, during recent years, for forgings of all types, it is not surprising, therefore, that important developments in forging equipment and practice have resulted, some of which are discussed by the author.

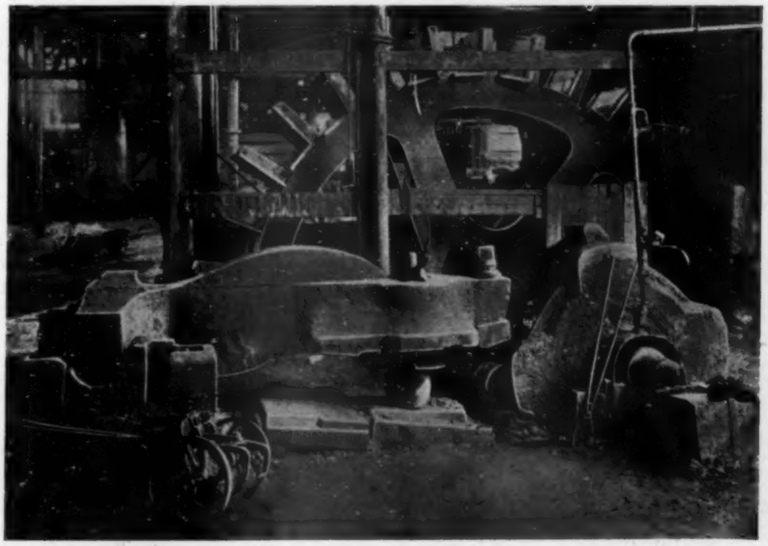


Fig. 1.—An early type of water-driven helve hammer, erected during the 17th century.

THE forging industry represents one of the oldest of the mechanical arts, and while the same fundamental principles apply to-day which governed the success or failure of the early craftsman, the methods of forging production have been mechanised and elaborated to meet modern requirements, and the art has been supplemented by the science. With the enormously increased demand for forgings of all types for aircraft, tanks, ordnance and transport during recent years there have been important developments in forging equipment and practice, and the many new and extended applications of forgings in engineering construction have involved the production of a large variety of unusual and complex types.

In quality also there have been exceptional requirements, necessitating the operation of comprehensive systems of control and inspection. A most significant development in modern forging practice is the increasing employment of metallurgical control over the quality of the forged product and progress in this connection has facilitated the production of a superior type of forging having maximum reliability under the most strenuous conditions of service.

Forging Hammers

The development of forging equipment has proceeded in pace with the requirements and ability of the engineer. When the early advances in the use of iron called for forgings of a size too large for the blacksmith's hammer, various mechanically operated hammers were introduced, frequently driven by water power. One of the early types of water-driven helve hammers is illustrated in Fig. 1. This particular hammer was erected at Kirkstall Forge about the 17th century for use in iron working and is still preserved for its historical interest.

The advent of steam power was followed by the invention of the steam-hammer which is generally credited to Nasmyth in 1842. This invention represented the greatest single advance in mechanical forging, and, by providing the means for the production of homogeneous forgings of a much greater size than had hitherto been possible, laid the foundations of the modern forging industry. For general purposes the steam hammer in its various forms remains the principle item of forging equipment. The basic design of the forging hammer has not altered greatly during recent years, although there have been many improvements in detail. There are two main types of steam hammers ; the arch-form or double frame hammer used for the heavier class of general forge work, and the overhanging or single-frame type applied to general smithy or the lighter forge work. The pallets or die surfaces of these hammers are usually flat so that the shape of the finished forging depends upon the manipulation of the work-piece and a few simple form tools.

Drop Forging

Although the invention of the steam-hammer and the development of its modern forms represent a series of events of major importance in forging history the full potentialities of forging as a quantity production method were not realised until the introduction of the impressioned die technique. For very heavy work, or work of a simple form where large quantities are not required, forging between flat dies is a satisfactory method, and may be the only possible method, but the shape of the forging so produced, however much it may bear testimony to the skill of the smith, can only be to

By courtesy of B. & S. Massey Ltd.

Fig. 2.—50-cwt. friction drop stamp with rigid guides.

tolerances which are wide by modern standards and close reproducibility is lacking. When forgings were required for the mass-production industries, it was essential to have a uniform product in which excess metal was reduced to a minimum.

By the use of dies having impressions specially cut to conform closely to the required shape of the finished article, forged parts can be duplicated in large quantities at a speed and accuracy which is not otherwise possible. It is believed that this method was first used in the manufacture of die-forgings for the mass-production of firearms but its products now find application in all types of automotive, aircraft and general engineering equipment.

The forging unit principally employed for this class of work is the drop-hammer or stamp which appears to have been introduced during the latter half of the 19th century, and the forgings so produced are described as "drop-forgings" or "stampings." Various types of drop-forging hammers are in use but all consist essentially of a heavy base and anvil which support the bottom die of a pair and a heavy ram or tup which carries the top die and moves between vertical guides. The two steel die blocks are so arranged with impressions machined in their contacting surfaces that when they meet the space enclosed represents the required shape of the finished forging. On the top frame-work of the hammer is the lifting mechanism for raising the tup.

In drop-hammer forging, the heated metal, which may have been given a preliminary rough forging under an ordinary light-forging hammer, is placed in the lower die, the upper die is then lifted with the tup and allowed to fall, the metal becoming forged to the shape of the impression in the dies by the force of the impact. Repeated blows are given until the metal is formed to the desired shape and size. The excess metal which is extruded between the dies as a thin fin or "flash" is removed from the stamping in a trimming operation. For the more complex shapes more than one set of impression dies will be required so that the forging is completed in progressive stages, the sequence of operations being designed to confer the best conditions of grain flow on the finished article.

The whole construction of the drop-hammer is necessarily massive, and in modern units close attention is paid to the provision of adequate and accurate guides to ensure long life of the wearing surfaces and close matching of the die impressions. Drop-hammers are usually classified according to the means employed for raising the tup, the types including friction drop stamps, steam and pneumatic drop stamps and board drop stamps. The friction drop stamp is widely used in this country and in this type the tup is attached by belts to a friction band encircling a rotating drum. When the driving cord is pulled the friction band grips the drum and in being carried round raises the tup. On release of the cord the friction band is disengaged and the tup falls freely, the intensity of the blow being regulated by varying the height of fall. An example of a modern friction drop stamp is shown in Fig. 2. Drop hammers of this type are produced in sizes of from 5 cwts. to 15 tons, this rating representing the weight of the tup.

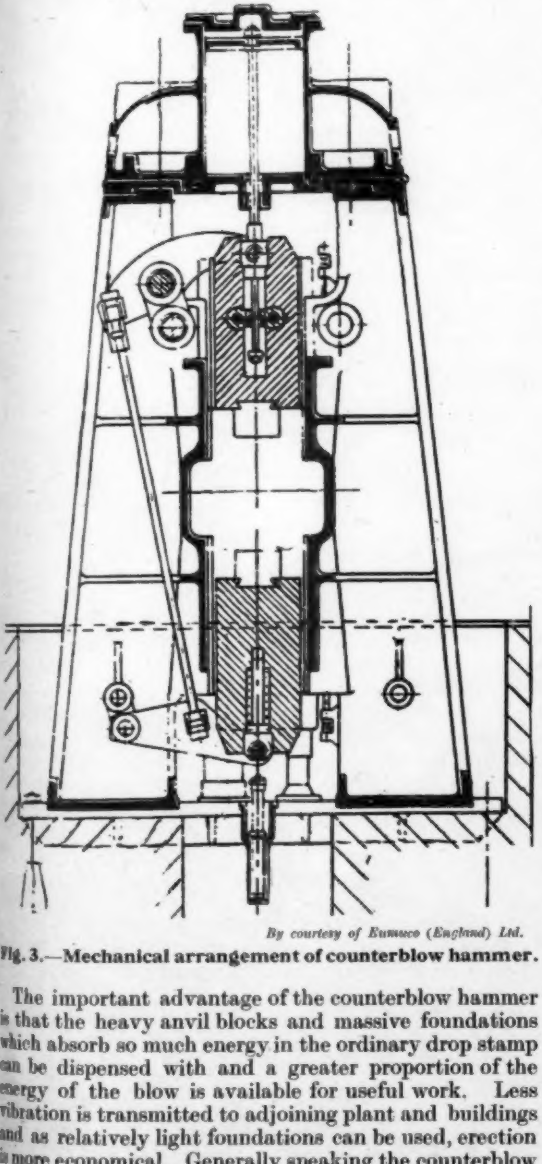
In the steam or pneumatic drop-hammer the tup is directly attached to a piston operating in a vertical cylinder on top of the hammer. The modern hammer of this type is usually arranged to be double-acting, that is in addition to using steam or compressed air for lifting, the drop is also made under power so that extra energy is imparted to the blow. The double-acting stamp strikes a considerably heavier blow than a gravity fall stamp of the same nominal rating, and as more blows per minute can be struck, a correspondingly higher output is possible. It is exceedingly flexible in operation and a particular advantage is the controllable nature of the blow, a sharp "live" blow being characteristic of this type of stamp. The power drop hammer has come into wider use in recent years, and for certain classes of work is preferred. The type is particularly suitable for multiple impression dies and can be used in the heaviest applications. Sizes up to about 20 tons rating are in use.

A design of gravity stamp which is fairly widely employed in the United States for the lighter classes of work, is the board drop hammer. In this unit the tup is fastened to maple wood boards which pass vertically between two rollers on top of the frame. These rollers rotate in opposite directions and are arranged to grip the boards and roll them upwards so raising the tup. At the top of the stroke the grip of the rollers is automatically released, allowing the tup to fall freely by gravity.

The Counterblow Hammer

An interesting development in die forging equipment has been the introduction of the counterblow hammer, the distinctive feature of which is the opposing movement of both top and bottom dies. In this type of hammer the stationary anvil block of the usual drop-hammer is replaced by a second tup which is arranged to have an upward motion between vertical guides. When the

hammer is in operation the upper tup with attached die block is driven downwards by an overhead steam or pneumatic cylinder, and simultaneously through suitable inter-connecting mechanism the lower tup is forced upwards, the work of forging being done by the impact of the two. In one form of counter-blow hammer the upper and lower tups are connected by flexible steel bands whilst in an alternative design which is now being used the motion is transmitted to the lower tup through a lever and tension rod system. This latter arrangement is illustrated diagrammatically in Fig. 3. The tups are of equal weight and move together at equal velocity.



By courtesy of Eumuco (England) Ltd.

Fig. 3.—Mechanical arrangement of counterblow hammer.

The important advantage of the counterblow hammer is that the heavy anvil blocks and massive foundations which absorb so much energy in the ordinary drop stamp can be dispensed with and a greater proportion of the energy of the blow is available for useful work. Less vibration is transmitted to adjoining plant and buildings and as relatively light foundations can be used, erection is more economical. Generally speaking the counterblow hammer is more readily adaptable to difficult ground conditions. Hammers of this type are suited to the production of a variety of closed die forgings and have been of particular service in the forging of crankshafts.

Press Forging

Hot press and upset forging constitute a further range of forging processes and serve a most important function in modern production. Press forging differs from hammer forging in that the metal is squeezed to shape in the press by the gradual application of pressure as distinct from the impact which is given under the forging hammer or drop-stamp.

Press forgings themselves may be divided into two main groups – the large hydraulic press forgings produced between flat dies, and the more compact precision forgings formed between closed dies, usually in a mechanical press. The hydraulic forging presses of up to several thousand tons capacity remain indispensable for the manufacture of large hollow forgings for seamless high-pressure drums and reaction vessels as well as many other types of forgings for general engineering and marine construction, but for the present it is proposed to restrict attention to the mechanical press employed in the production of small and medium sized forgings to close dimensional tolerances on a high output basis.

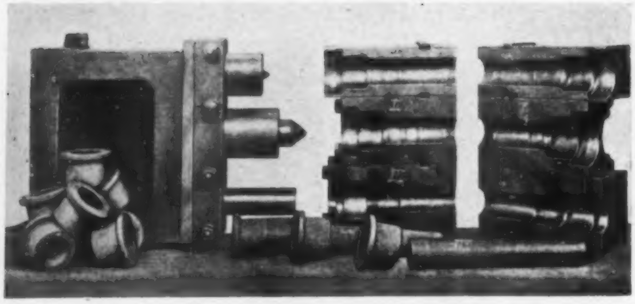
The general form of mechanical press acts vertically, the heated stock being placed in the bottom die and formed to shape by the downward movement of the ram to which is attached the upper die. Shaped impression dies are used similar to those of the drop-forging hammers and, in fact, the method is an alternative to drop-forging in many cases.

The modern mechanical forging press is a relatively high-speed unit, and improvements in construction and design have been in the direction of obtaining the utmost rigidity and accuracy of die alignment with rapidity of action not only during the actual forming motion but also in the feeding and ejection operations. There should be instantaneous starting and the whole sequence of operations synchronised so that the hot metal is a minimum of time in the dies. The various mechanical improvements which have been embodied in the modern precision forging press have greatly increased the practical possibilities of this method and established it as an accurate and economical production process.

Possibly the wider range of application of the press is in the production of non-ferrous forgings where more advantage can be taken of the extrusion properties of the softer metals, although a very large number of steel forgings are being produced in this manner, and there are certain advantages in press methods where it is possible for them to be employed. For suitable classes of work the production rate under the mechanical press is quite high, and, as means can be provided for positive ejection of the forging, it is possible to use very small draft angles so that less material is required than with other forging methods and there is a corresponding saving of time in subsequent machining operations. Symmetrical forgings are particularly suited to die press methods, whilst for hollow or shell-type forgings extrusion dies can be employed, a similar method also being applicable to shanked or stemmed parts such as mushroom-valve forgings.

Machine Forging

The forging machine or upsetter is basically a double-acting horizontal press. In the standard type of forging machine, the heated stock, usually bar material, is gripped horizontally between a pair of recessed dies and the heading or piercing tool advances and forces or



By courtesy of Eumuco (England) Ltd.

Fig. 4.—Set of split dies and headers for upset forging machine.

upsets the metal into the die cavity. On completion of the upsetting operation the heading tool recedes and the gripper dies open, the work then being removed from the machine if completed, or transferred to the next position in the dies if more than one pass or forming operation is required. Fig. 4 shows a pair of split dies with punches and Fig. 5 illustrates the sequence of a typical upsetting operation.

The forging machine has been developed from the old bolt-making machines. Gradual improvements and refinements in bolt-heading methods led to the adoption of the equipment for general upsetting work, and modifications have been made in the design and construction to give the wide adaptability which is characteristic of the modern type of forging machine. With the growth of the motor industry and the introduction of mass-production methods the upset forging machine came into practically universal use as a means of producing large quantities of special type forgings having low scrap loss and reduced machining costs.

The modern high-duty forging machine is of extremely rugged construction, and possesses much greater power and has much larger die capacity than its predecessors. The strength and rigidity of construction which are essential for maintaining accuracy of operation are secured by making the main frame or body of a heavy and substantially braced one-piece steel casting. Other important features of the machine include a heavy-duty pneumatic friction clutch; double-action gripping movement to ensure that the dies remain firmly closed during the forging operation; automatic lubrication, and safety devices for the protection of the operator and the machine. Forging machines are rated according to the die capacity, the maximum size at present being about 9 in.

Although the forging machine was originally introduced as an upsetting unit and as such still has its chief function the advances in its design and construction in recent years have been responsible for an extensive increase in its field of application. The power and speed of the modern machine, coupled with the rigidity and accuracy of die and tool alignment and improved tool steels enables an extremely wide variety of forgings to be produced at high outputs and to very closely maintained dimensional limits. Many examples of forgings which at one time would have been considered impracticable, are now being manufactured in the forging machine on a mass-production basis.

The deep piercing process is a particular example of how a difficult forming operation can be simplified by the application of sound principles in the forging machine. Formerly deep holes were produced in forgings by an extrusion process in which the hot metal was displaced backwards in a direction opposite to the movement of the punch. This counter-movement of metal and punch caused excessive wear on the tools and dies, particularly with steel, and the power requirements were high. In the present progressive deep piercing process the dies and piercing tool are designed to displace the hot metal outwards to the sides of the dies in a series of passes so causing less wear on the tools and dies and furthermore reducing the power requirements. By this method the grain structure is also improved.

The full application of the machine depends to a very large extent on the skill of the die designer, and the obvious tendency is to obtain increased outputs by reducing the number of passes required so that multi-operation forgings may be finished at a single heat, an arrangement which is greatly assisted by the quick starting and high speed operation of the machine.

In addition to its use as an independent unit, the forging machine also serves a most valuable purpose in the preparation of upset blanks intended for final stamping in the drop-hammer, or for upsetting operations after drop-forging such as flanging the flywheel ends of crankshaft forgings.

Quality Control

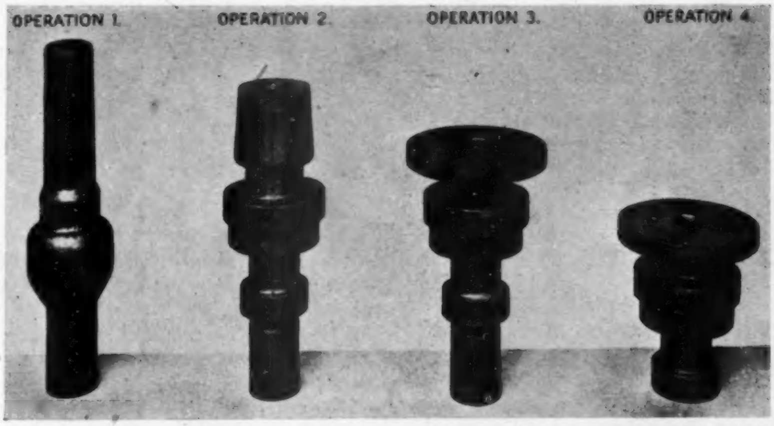
Close supervision of all factors affecting the quality of the finished article has become an important feature in the manufacture of forgings. This applies particularly to aircraft forgings where in view of the special service conditions and the need for absolute reliability, quality control is now a routine procedure. Strict metallurgical supervision is exercised at all stages in the production of aircraft forgings from the manufacture of the steel to the finished article.

The steel itself before being released for aircraft purposes is checked for chemical composition; physically tested for response to heat-treatment and macro-etched for general soundness and freedom from external and internal defects. Micro-examination is also carried out for estimation of the grain-size and assessment of the non-metallic inclusion content, and in this latter connection may be supplemented by magnaflux inspection of specially prepared samples.

One of the most important factors to which attention must be paid in the production of quality forgings, whether aircraft or non-aircraft, is accurate temperature control during the re-heating and forging operations. Exposure to excessive temperatures is liable to cause structural damage to the steel with varying degrees of deterioration in mechanical properties. For similar reasons prolonged soaking at temperature is to be avoided, although the period must be sufficient to give the uniform heat-penetration which is essential for an even flow of metal during forging. Where the requirements are too exacting for the judgment of the forger to be sufficiently reliable, pyrometer control and close supervision of furnace conditions by trained observers becomes necessary. Further precautions are called for in cooling after forging as a number of the alloy steels are susceptible to the effects of internal changes and a slow-cooling schedule is required. After descaling by shot-blasting or pickling, the forgings are visually

inspected for surface conditions and dimensions, and in certain cases magnetic methods may also be employed.

Arrangements are usually made for the grain-flow to be checked periodically by the examination of etched sections prepared from the forgings. This factor receives special attention because of the important effect of the flow-line direction on the properties of the forgings in service. The action of the forging operation on the structure of the metal should be to refine the grain and distribute the "fibre" or flow-line formation so as to give the optimum mechanical properties, particularly with reference to "toughness" which implies resistance to shock-loading conditions and high endurance. In designing a forging therefore, and in planning and supervising its production, there must be a close knowledge of all considerations appertaining to its intended application.



By courtesy of Eumuco (England) Ltd.

Fig. 5.—Sequence of a typical upsetting operation.

Auxiliary Equipment

Whilst it has not been possible in this brief review of forgings production to deal with all aspects of a very wide subject it should be mentioned that in addition to the improvements made in the forging units themselves, there have been advances in many other directions, all of which have contributed to the general progress. Furnace types have been developed and new methods of heating introduced; work-handling equipment has been improved for speedier operation, and plant layouts have been re-designed to give uninterrupted flow of work through the shops. In general, the main trend of the advances in forging practice have been directed towards obtaining increased production per unit of equipment, and combining speed and economy with the accuracy of operation necessary in the manufacture of a high quality product.

Sir William Larke to Retire

SIR WILLIAM LARKE, K.B.E., D.SC., is retiring from the position of Director of the British Iron and Steel Federation, on March 31 next. He was appointed the Director of the National Federation of Iron and Steel Manufacturers in 1922, and has been associated with the progressive organisation of the industry since that date, culminating in the present British Iron and Steel Federation and the British Iron and Steel Research Association.

Sir William Larke has made a complete recovery from the major operation he underwent early last year. He has resumed, and will continue his various public and other activities.

Retirement of Mr. E. C. Evans

MR. E. C. EVANS, B.Sc., F.R.I.C., F.Inst.F., who for many years has been closely associated with scientific research in both the fuel and iron and steel industries, recently retired from the British Iron and Steel Research Association, in the organisation of which he played an active part. He is, however, continuing to undertake scientific and technical activities in an advisory capacity to a range of industries.

Until recently, Mr. Evans was Technical Secretary to the Iron and Steel Industrial Research Council, which early in 1945 was re-organised as the British Iron and Steel Research Association. In the past 20 years he has done much to foster the spirit of co-operation which has developed in the fuel and metal industries, where technical and research workers freely and frankly exchange experience and knowledge for the benefit of the industry as a whole. During his long association with the iron and steel industry he has initiated, in co-operation with the leaders of technical thought in the trade, developments which played a most important part in the successful prosecution of the war.

In the fuel drive, which has become so important to-day, Mr. Evans was responsible for the formation of at least eight District Committees, the reports of several of which have received wide recognition. As one of the founders of the Institute of Fuel, he contributed largely to the creation of an organisation which has successfully promoted and developed "a fuel sense" among industrialists, stimulating a steady and progressive improvement in fuel efficiency. In association with the late Professor R. E. Wheeler, he founded, in 1926, the Midland Coke Research Committee, representing the coke-making and using interests.

During the war it was decided to replace the Iron and Steel Industrial Research Council, which was essentially a committee of the British Iron and Steel Federation, by an autonomous research association, financed largely by the B.I.S.F., an income of £250,000 per annum being assured to the Research Association by the industry at the outset. Mr. Evans took an active part in the organisation of the new Association, and he was asked to defer his retirement until Sir Charles Goodeve, O.B.E., D.Sc., F.R.S., the Director of the Research Association, could be released from his official duties at the Admiralty as Assistant Controller in Charge of Research and Development. Sir Charles Goodeve took up his appointment on October 1, 1945.

Some Recent Appointments

Mr. Victor Malcolm has been appointed Representative in the United Kingdom for the Republic Steel Corporation, succeeding the late Mr. W. E. Knight. He will also act as General Manager and Supervisor of the Corporation's interests in Western Europe. London offices have been established at 115, Park Street, W. 1. (Telephone : MAYfair 4950).

Mr. Malcolm served with Dorman, Long and Company, Ltd. until 1935, when he became Secretary of the British Iron and Steel Federation ; he later became associated with the British Iron and Steel Corporation, Ltd., from whom he has been on loan to the Ministry of Supply, Iron and Steel Control, for the duration of the war.

Mr. E. Kenneth Hughes has been appointed Commercial Manager of the Whitehead Iron and Steel Co., Ltd., Newport, Mon. Mr. Hughes commenced his career with the company 28 years ago. During the war he was loaned by the company to the Iron and Steel Control, which he served in the capacity of Deputy Director for Re-Rolled Products.

Mr. E. R. Davies, F.Inst.P., Director of Research, Kodak, Ltd., has been appointed Hon. Treasurer of the Institute of Physics, to succeed the late Major C. E. S. Phillips.

Mr. I. A. Bailey, General Manager of the Mond Nickel Company's refinery at Clydach, South Wales, since 1936, has been appointed Managing Director of Henry Wiggin and Company, Ltd., a wholly-owned subsidiary producing malleable nickel and nickel-containing alloys in semi-manufactured forms.

Mr. J. O. Hitchcock, of the Nickel Company's Development and Research Staff, has been appointed Personal Assistant to the Managing Director of Henry Wiggin.

Mr. R. M. Parry, Sales Manager of Henry Wiggin and Company, Ltd., manufacturers of malleable nickel, Monel, Inconel, and other nickel-containing alloys, has been appointed Sales Assistant to the Managing Director of The Mond Nickel Company, Ltd.

Mr. R. E. Ansell, formerly Technical Service Manager, has been appointed Sales Manager of Henry Wiggin and Company, Ltd.

Mr. A. Chester Beatty, Jnr., and Dr. W. T. Griffiths, have been appointed Directors of The Anglo Metal Company, Ltd. Mr. R. L. Prain, O.B.E., has been elected Chairman of the Board.

Mr. Roger F. Mather has been appointed chief metallurgist of the Kaiser-Frazer Corporation, Willow Run, Michigan. Mr. Mather, whose father is a Director of Skinningrove Iron and Steel works, has relinquished a similar position with Willys-Overland Motors, Inc., Toledo, Ohio, to take up this new appointment.

Prof. Eric K. Rideal, of Cambridge University, will succeed Sir Henry Dale, O.M., as Fullerian Professor of Chemistry in the Royal Institution, and Director of the Davy-Faraday Research Laboratory. Sir Henry retires from these positions on September 30 next.

Sir James French has been appointed chairman of the Governors of the Royal Technical College, Glasgow, in succession to Dr. Robert Robertson, who has retired for health reasons.

Mr. A. F. C. Gardner has been appointed Northern Area Manager for Gibbons Bros., Ltd., of Dudley. For some 13 years, Mr. Gardner was technical representative with Newton Chambers and Co., Ltd.

Mr. James Stuart Duncan of The Massey Harris Company, Ltd., of Toronto, has been elected a Director of The International Nickel Company of Canada, Ltd. Mr. Duncan is Chairman of the Board of The Massey Harris Company, and is also on the boards of various American and Canadian companies, including the Canadian Bank of Commerce, Toronto.

Retirement of Mr. Roland Finch

The retirement (as from January 1, 1946) of Mr. Roland Finch, Joint Managing Director of Imperial Chemical Industries' Metals Division, closes a career of 43 years' active association with the British non-ferrous metals industry. Mr. Finch has held the post of Joint Managing Director of I.C.I. Metals since 1936.

Born in 1882, Mr. Finch joined Kynoch, Ltd., in 1902, as an assistant to the General Manager, after graduating in mechanical engineering at the City and Guilds College, London. From 1906 to 1914, he travelled extensively in America and Europe as Kynoch's foreign representative. During the first world war, Mr. Finch was Labour Manager for all the factories controlled by Kynoch, Ltd. When Kynoch absorbed the King's Norton Metal Co. and the Birmingham Metal and Munitions Co., he was appointed Commercial Manager of the Metals Department, and occupied this post at the time of the merger of the Kynoch group into I.C.I. Metals, Ltd., in 1926.

Although he now relinquishes many I.C.I. commitments, Mr. Finch will remain in close touch with the British non-ferrous metal industry. He is a member of the Grand Council and of the Export and International Relations Committee of the Federation of British Industries. He is also a member of the Council and Executive Committee of the British Non-Ferrous Metals Federation, and Chairman of the International Relations Committee. Mr. Finch will continue to reside at Wissington Grange, Layland, near Colchester, where he has been farming for many years.

Exhibition of German Aeronautical Developments

An exhibition of German aeronautical developments was opened on February 14, at the Science Museum, South Kensington. This instructive and highly interesting exhibition, which is being held under the auspices of the Ministry of Education, is admission free and will be open on weekdays from 10 a.m. to 6 p.m., and Sundays from 2-30 p.m. to 6 p.m.

It will remain open for three months. This exhibition was held at The Royal Aircraft Establishment last autumn but it was felt to be of the utmost importance that students and technicians as well as the general public should have an opportunity of a close-up inspection of what the German aircraft industry achieved.

The exhibits, which are provided by the Royal Aircraft Establishment of the Ministry of Aircraft Production, are selected from the most instructive examples shown at Farnborough. They include a number of typical German military aircraft, including a jet-propelled fighter, flying bomb, the gyro-kite for use with U-boats, a piloted V1, a V2-rocket and radio-controlled rocket weapons. Many components and photographs will be exhibited showing to the general public for the first time, full details of enemy aeronautical development.

Estimation of Zinc in Aluminium Alloys by Means of Quinaldinic Acid

By J. H. Bartram and P. J. C. Kent

A method has been devised whereby it is possible to estimate the zinc content of all classes of aluminium alloys using quinaldinic acid, over a range of 0–14% zinc. The method is accurate and reasonably fast, and has been adapted for routine analysis.

BY 1942 aluminium scrap had become so contaminated with zinc, that it was not possible to carry out the necessary number of analyses using the normal electrolytic method.[1] Various published electrolytic methods[2, 3, 4] were tried and also the zinc-mercury thiocyanate and oxide-sulphide methods.[5, 6]. In the hands of semi-skilled routine workers, none of these methods gave reliable results. The electrolysis machines were already working to capacity on the copper estimations, and it was decided that an accurate and rapid gravimetric method would be most suitable, if one could be found.

Principle of the Method

With an alloy containing 0·1% zinc only 1mgm. is available for isolation from the usual 1-gm. sample. Using an electrolytic method, an increase of weight of 1 mgm. on a relatively heavy cathode has to be determined accurately and alteration in the zero of the balance and the weight of the cathode can cause serious errors. If the zinc can be precipitated as an organic complex of high molecular weight, much of this error is avoided.

Zinc forms a complex with quinaldinic acid, which contains only 15·29% zinc. Thus 1 mgm. of zinc in the sample produces $6\frac{1}{2}$ mgm. of complex for weighing. Estimation of zinc with quinaldinic acid seemed only to have been applied on mixtures of pure salts, such as zinc and cadmium, zinc and copper, and zinc, cadmium, and copper.[8, 9, 10, 11]. Aluminium alloys contain a large number of elements which interfere with the reaction, and these have to be removed. These elements include, iron, silicon, manganese, magnesium, copper, tin antimony, and lead ; aluminium itself does not interfere. It was found possible to remove all these interfering elements except silicon, by precipitating with sodium hydroxide and hydrazine. This alkaline reduction produces a finely-divided metallic precipitate, which is easily filtered off on a Whatman No. 3 filter paper. The zinc quinaldinate complex can be filtered off quite rapidly on a sintered glass crucible, porosity 4, with suction.

The zinc quinaldinate complex is precipitated in a relatively narrow pH range, and only one indicator has been found to be satisfactory in this range, methyl red-methylene blue. The colour change is hard to follow in artificial light, and therefore the pH adjustment should be carried out in daylight, or some form of " day-light " lighting.

An experienced operator can handle 8–12 of these estimations at one time, but an attempt should not be made to exceed 12, otherwise it is found that accuracy rapidly falls off. Twelve estimations occupy about four hours.

Experimental

Reagents Required :

Ammonium chloride. A.R.
Sodium hydroxide. A.R.
38·5% tartaric acid solution.
3N hydrazine hydrate solution.
0·02% methyl red in 50/50 alcohol and water.
0·02% methylene blue in water.

Acid mixture:
- 25 ml. hydrochloric acid.
- 15 ml. sulphuric acid.
- 10 ml. nitric acid.
- 50 ml. water.

Quinaldinic Acid Solution (6 gms. per litre) ;—Dissolve 6 gms. of acid in 300–400 ml. hot distilled water, and neutralise with sodium hydroxide solution, using the above two indicators, and make up to 1,000 ml.

Weigh 1 gm. of the alloy into a 450-ml. conical beaker, and add 30 ml. of the acid mixture. When the reaction has subsided, evaporate the contents of the beaker to dryness on the hot plate, and bake for a short time to ensure the insolubility of the silica. Moisten the white mass in the bottom of the beaker with 10 drops of 50/50 sulphuric acid, and 50–100 mls. of distilled water, depending on the amount of silicon present. Boil to break up the mass, and dissolve all soluble salts. Filter off the silicon through an 11 cm. Whatman No. 40 filter paper, and wash three to four times. When washing it is best to allow the filter paper to almost empty before washing again. Collect the filtrate in a 450 ml. conical beaker containing three-quarters of a stick (approximately 15 gms.) solid sodium hydroxide and 5 ml. of 3N hydrazine hydrate. After washing, the bulk of the liquid in the beaker should be approximately 150 ml.

Raise the contents of the beaker to boiling point, maintain for 1 min., and filter off the metallic precipitate through a 12·5 cm. Whatman No. 3 filter paper. It is essential that boiling should be continued for at least 1 min., to destroy any excess of hydrazine, which would interfere with the indicator at a later stage. The bulk of the filtrate should now be 250–300 mls.,

1 " Determination of Zinc in Aluminium Alloys." W. Stross and G. H. Osborn. *Light Metals*, July, 1944.
2 " Electrolytic Determination of Zinc in Aluminium Alloys." G. H. Osborn. *J.S.C.I.*, vol. LXII, p. 58-60.
3 " Chemische Analysen-Methoden für Aluminium und Seine Legierungen." *Aluminium Zentrale.* Second Ed., 1938. Blatt Zn. 1.
4 A. Cohen. Helv-Chim-Acta. 1942. 25. 325.
5 " Analysis of Aluminium and Its Alloys." British Aluminium Co., 1941. pp. 36-38.
6 " Chemical Analysis of Aluminium." Aluminium Company of America. 1941. pp. 42-45.
7 " Organic Reagents for Metals." Hopkin and Williams. p. 123.
8 *Z. Anal. Chem.* 96, 418 seq. 1934. P. Ray.
9 *Z. Anal. Chem.* 95, 400 seq. 1933. P. Ray.
10. *Michrochem.* 17, 11 seq. 1935. P. Ray and M. K. Bose.
11 *Analyst.* 64, 14 seq. 1939. R. J. Shennan.

and if it is less, make up with distilled water. Otherwise, tartrates will precipitate at the same time as the zinc quinaldinate. To this filtrate add 20 ml. of 38·5% tartaric acid solution, and make acid with hydrochloric acid. Then add approximately 15 gms. of solid ammonium chloride, and 0·3 ml. each of 0·02% methyl red and 0·02% methylene blue solution, as an indicator. The precise amount can be varied slightly to suit the light or individual preference, but equal volumes of each indicator must be employed, or the colour change is not true. Add dilute ammonia dropwise, until the indicator turns greenish blue. This indicates a pH of 4·6–4·65 measured at 15° C. During this procedure the solution should be maintained at approximately 75° C. Then add 30 ml. quinaldinic acid solution.

Allow the beaker to stand on a warm plate, to keep its contents at 75°–80° C. for a further 30 min. to complete the precipitation of the zinc quinaldinate.

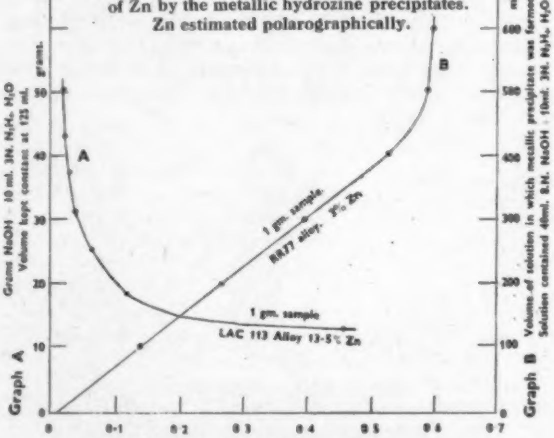


Fig. 1.—Graphs showing factors affecting occlusion of Zn by the metallic hydrozine precipitates. Zn estimated polarographically.

Filter off the zinc quinaldinate on a sintered glass crucible, porosity 4, wash well with distilled water, and finally once with alcohol. Dry in a thermostatically controlled oven at 125° C. for 10–20 min., depending on the quantity of zinc present. Cool in a desiccator, and weigh. Replace the crucible on the suction filter, and dissolve the zinc quinaldinate by pouring over it warm dilute nitric acid. The zinc quinaldinate absorbs some colour from the methylene blue, and it is therefore quite easy to see when it has dissolved. Wash with distilled water, and finally once with alcohol. Dry in the oven for 10 min., then cool and re-weigh. The difference between the two crucible weights, is the weight of the zinc quinaldinate. This procedure allows for any silica which may have come through from the first stage, and also for any filter paper fluff or similar material retained by the crucible. The amount of such material is usually very small, and in practice, unless the zinc content of the alloy is less than 0·3%, this double weighing procedure is not necessary, if the weight of the crucible is known before the filtration. The increase in weight can then be taken as the weight of the zinc quinaldinate complex, which contains 15·29% zinc.

For alloys containing 0–3% zinc use a 1 gm. sample, 3–6% zinc a 0·5 gm. sample, and 6–14% zinc use a 0·25 gm. sample. This ensures complete precipitation

TABLE I.
STANDARDS.

Alloy	Electrolysis	Polarograph	Quinaldinic Acid	No. of Estimations	Maximum Variation in Quinaldinic Figures	% of Amount
D.T.D. 479 ...	—	0·04	0·03	6	Nil	0
B.A. 35	0·21	0·21	0·21	90	0·015	7
L.A.C. 10	—	0·65	0·65	12	0·02	3
Gp. 11 Store ...	—	1·00	0·96	6	0·02	2
D.T.D. 428 ...	—	2·06	2·01	8	0·025	1·2
D.T.D. 428 ...	—	3·07	3·03	6	0·03	1
R.R. 77	2·96	3·00	3·00	150	0·03	1
L.A.C. 113	13·42	*12·90	13·55	10	0·14	1

* This % of zinc is outside the usual range of polarograph, and the result was obtained by extrapolation.

TABLE II.
ALLOY D.T.D. 424.

Charge No.	Polarograph	Spectrograph	Quinaldinic Acid
D.K. 89	0·17	0·15	0·18
,, 92	0·12	0·15	0·13
,, 298	0·15	0·14	0·20
,, 299	0·16	0·14	0·18
,, 300	0·13	0·12	0·15
,, 389	0·17	0·18	0·18
,, 392	0·19	0·18	0·20
E.K. 60	0·17	0·12	0·14
,, 61	0·17	0·16	0·15
,, 108	0·11	0·08	0·12
,, 109	0·15	0·08	0·16
,, 111	0·16	0·08	0·18
,, 201	0·07	0·05	0·09
,, 202	0·09	0·07	0·07
,, 204	0·11	0·10	0·11
,, 205	0·10	0·14	0·11
,, 207	0·09	0·05	0·08
,, 209	0·09	0·05	0·08
,, 210	0·11	0·06	0·18
,, 284	0·14	0·08	0·16
,, 287	0·17	0·15	0·17
,, 288	0·14	0·10	0·14
,, 289	0·11	0·10	0·12
,, 384	0·14	0·13	0·15
,, 385	0·15	0·13	0·16
,, 387	0·17	0·16	0·17
,, 325	0·11	0·10	0·12
,, 326	0·12	0·11	0·12
,, 327	0·12	0·11	0·14
,, 379	0·10	0·10	0·12
,, 380	0·17	0·11	0·16
,, 381	0·15	0·10	0·13
,, 383	0·15	0·12	0·11
,, 434	0·13	0·10	0·10
,, 435	0·17	0·10	0·14
,, 437	0·16	0·14	0·17
G.K. 8	0·19	0·18	0·21
,, 9	0·20	0·18	0·21
,, 13	0·17	0·17	0·15
,, 14	0·16	0·16	0·13
,, 10	0·19	0·20	0·15
,, 11	0·19	0·20	0·16
,, 16	0·11	0·09	0·12
,, 17	0·10	0·09	0·09

of the zinc quinaldinate. Each 30 ml. quinaldinic acid solution is equivalent to 3% zinc.

Comments on Procedure

The first filtrate is collected on solid sodium hydroxide, because it is found that the percentage of zinc occluded by the metallic precipitate varies with the bulk of the solution in which the precipitation takes place. The alkalinity of the solution also has an effect. The greater the concentration of sodium hydroxide, the smaller the occlusion (Fig. 1). In practice it was found that the amount of sodium hydroxide quoted above in the presence of hydrazine gave negligible loss, even with alloys containing 13·5% zinc, if the volume was kept within the specified limit.

The strength of the tartaric acid solution provides a compromise so as to obtain a sufficient buffering action together with the prevention of the precipitation of the aluminium salts present, and also avoids undesired precipitation of tartrates, should the temperature of the solution drop to 60° C. or less during working.

Results

This method of estimation has been in operation in the Slough Laboratory of Messrs. International Alloys, Ltd., for routine work, for a period of 18 months, and many thousands of estimations have been carried out. Throughout this period there have been some hundreds of checks with polarographic, spectrographic, and electrolytic methods. Tables 1 and 2 show some ot these results.

Zinc has been estimated in the following types of alloys quite successfully, using the above method.

6 L. 1 ..	D.T.D. 165	L.A.C. 10	R.R. 50	4% Fe Hardener.
3 L.5 ..	„ 300	„ 112	„ 53	20% Ni „
3 L.8 ..	„ 304	„ 113	„ 56	25% Cu „
4 L.11 ..	„ 324	Y. Alloy	„ 59	50% Cu „
2 L.33 ..	„ 364	B.A. 35	„ 77	5% Mn „
	„ 424	S.P.A.		10% Mn „
	„ 428	LO-EX		20% Si „
	„ 479	A7		5% Ti „

At first we experienced great difficulty in obtaining adequate supplies of quinaldinic acid. Eventually Messrs. L. Light and Co., Ltd., of Wraysbury, Bucks., undertook to supply us in sufficient quantity to enable the method to be put into routine use.

All quinaldinic estimations carried out by the same operator over a period of two months on a series of charges of D.T.D. 424 Alloy produced during that period. Not more than three estimations on any one day, no result being omitted.

We would like to record our thanks to our colleagues Mr. Osborn and Dr. Stross, for carrying out a very large number of polarographic and electrolytic checks, and for helpful criticisms. We also wish to thank the directors of Messrs. International Alloys, Ltd., in whose Slough Laboratories this work was carried out, for permission to publish this paper.

Correspondence

Static Tension Energy

The Editor, METALLURGIA.

Sir,

Further to my letter in your September, 1945, issue, your readers may be interested in the following strain analysis of the test results to which Dr. A. C. Vivian referred me.

In my view, true strain means elongation divided by original length; true stress means load divided by actual cross-section, and nominal stress means load divided by original cross-section. The analysis is based on a view of the plasticity of steel set out in detail in my paper, "Plasticity," January 1945 in the Library of the Institution of Civil Engineers. The analysis conflicts with the opinion which it appears from his writings Dr. A. C. Vivian holds regarding the best way of expressing true strain and stress.

I think that exponential strain method introduces unnecessary complications, and believe the calculation of static tension energy is more easily solved using true strain $\left(\frac{A_0}{A} - 1\right)$ and the relation $f = s^m$, where f = stress ratio, s = strain ratio and m = plastic index. Note particularly that this is a relation connecting the ratios of stresses and strains to their limiting values in tensile failure.

It follows from this $f = s^m$ relation, and from principle (d) of my previous letter* that:

$$F_a = \frac{\text{U.T.S.} \quad (1 + s_u \cdot S_a)}{s_u{}^m} = \text{failure tensile stress,}$$

$$\text{and } S_a = \frac{1}{1 - \%\ \text{RA}/100} - 1 = \text{failure tensile strain.}$$

where s_u = strain ratio at the U.T.S.—*i.e.*, the point at which the nominal stress-strain line is maximum, so that $s_u \cdot S_a$ = strain at U.T.S. It follows also that

$$m = \frac{s_u \cdot S_a}{1 + s_u \cdot S_a}$$

For practical purposes, I use a chart to read off corresponding values of f and s for various values of m, and another chart to read values of the ratio F_a/U.T.S. in terms of S_a and m. Values of S_a and of m, respectively, are obtained by single settings of a slide rule using the relations stated.

The energy or work done to break a tensile bar is made up of the work done in stretching the bar approximately uniformly to the U.T.S., and of the work done in "necking" it to failure. In symbols the total stretch is given by:

$$\begin{array}{lcl} L.s_u \cdot S_a + \quad B & = & L.p/100 \\ (\text{uniform}) + (\text{necking}) & = & (\text{Total}), \end{array}$$

where L = gauge length and p the percentage elongation on that gauge length, and B = "necking" stretch from U.T.S. to failure. The work done on the bar is the mean nominal stress to the U.T.S. multiplied by the original area of bar (here ·0491 sq. in.), and by the extension to the U.T.S. plus the mean nominal stress from U.T.S. to failure multiplied by the original area and by the "necking" stretch B. The test measurements of the steel under review are taken with due acknowledgements to the authors from *The Engineer*—September 10, 1943, "Some Tensile Shock Properties of Carbon Steels"—F. V. Warnock, Ph.D., and J. B. Brennan, Ph.D.," as follows:

U.T.S. 24·2 tons/sq. in., percentage elongation 35% on 4-in. length of 0·625 in. dia., static energy 550 in. lb., static extension 0·26 in. on a test piece of 0·25 in. dia. of 0·46 in. parallel length with $\frac{5}{16}$ in. radius fillets, bringing the diameter up to $\frac{13}{16}$ in. at the enlarged ends.

Then, using the stretch equation above, accepting the principle of geometrical similarity, and taking the parallel length of 0·46 in. of the test specimen as the equivalent gauge length:

$$4 \times s_u \cdot S_a + B = 4 \times 0{\cdot}35$$

$$0{\cdot}46 \times s_u \cdot S_a + \frac{0{\cdot}25}{0{\cdot}625} \times B = 0{\cdot}26 \text{ in.}$$

$$\text{whence } s_u \cdot S_a = 0{\cdot}265, \text{ whence } m = \frac{0{\cdot}265}{1{\cdot}265} = 0{\cdot}210$$

$$\text{and } B = 0{\cdot}340 \text{ in.}$$

Then the "necking" extension of the test specimen of 0·25 in. dia. is $\frac{0{\cdot}25}{0{\cdot}625} \times 0{\cdot}340$ in. $= 0{\cdot}138$ in., the extension to the U.T.S. is $0{\cdot}46 \times s_u \cdot S_a = 0{\cdot}122$ in., total stretch $= 0{\cdot}138$ in. $+ 0{\cdot}122$ in. $= 0{\cdot}26$ in., and $S_a = \frac{1}{1 - 0{\cdot}682} - 1 = 2{\cdot}15$.

The true stress-strain line and the nominal stress-strain line are related by the $f = s^m$ equation, so that the ratio $\frac{\text{Mean nom. stress to U.T.S.}}{\text{Ultimate Tensile Strength}}$ can be calculated

* September issue, 1945, p. 198.

for any value of the strain to U.T.S. ($s_u \cdot Sa$). Values are :

$s_u \cdot S_a$	0·05	0·10	0·15	0·20	0·30	0·40
$\frac{\text{Mean nom. stress}}{\text{U.T.S.}}$	0·990	0·962	0·948	0·938	0·925	0·916

Owing to the enlarged ends and shortness of the test piece relative to its diameter, the so-called "uniform" stretch to the U.T.S. is tapered near the grips so that some load less than the mean nominal stress times the original cross-sectional area must be used in the calculation of energy of "uniform" stretch to U.T.S. It has here been assumed that the mean stress to U.T.S. is 10% less than as calculated from the assumption of uniformity. Then energy or work done to U.T.S. $= 0 \cdot 90 \times 24 \cdot 2 \times 0 \cdot 929 \times 0 \cdot 0491 \times 0 \cdot 122$ in. $\times$ 2240 = 272 in. lb. The mean nominal stress from U.T.S. to failure is approximately the mean of the U.T.S. and the nominal breaking stress $= \left(\frac{F_a}{1 + S_a}\right)$. Here U.T.S. = 24·2 tons/sq. in., whence $F_a = \frac{\text{U.T.S.}\ (1 + s_u \cdot S_a)}{s_u{}^m} =$ 47·4 tons/sq. in., and breaking stress (nominal) $= \frac{47 \cdot 4}{3 \cdot 15}$ = 15·0 tons/sq. in. Then mean stress (nom.) $= \frac{24 \cdot 2 + 15 \cdot 0}{2} = 19 \cdot 6$ tons/sq. in. ; and energy or work done from U.T.S. to failure $= 19 \cdot 6 \times 0 \cdot 0491 \times 0 \cdot 138$ in. $\times\ 2240 = 298$ in. lb.

Total energy = 272 + 298 = 570 in. lb., as compared with the measured value of 550 in. lb. for this steel A.

Applying exactly the same procedure to the other nine steels for which measurements are recorded in the report, "Some Tensile Shock Properties of Carbon Steels," the following results are obtained :

	A	B	C	D	E	F	G	H	I	J
F_a. tons/sq. in.	47·4	53·2	52·9	54·8	55·5	58·7	62·0	63·0	65·2	64·5
S_a	2·15	2·10	1·18	1·25	1·21	1·04	0·89	0·78	0·48	0·52
m	0·210	0·216	0·156	0·146	0·165	0·150	0·157	0·133	0·114	0·079
Static energy in lb. Calc.	570	611	616	671	677	694	647	682	575	593
" " " Measure	550	616	708	674	663	723	672	688	571	550
Error in calc.	+20	−5	−92	−3	+14	−29	−25	−6	+4	+43

Eight of these ten results are within the limits of material variation and/or experimental error. The calculated energy value of Steel C is very low, but it is observable that this steel is remarkable in that the measured static energy is within 2½% of the product of U.T.S. and cross-section and extension as measured, whereas in the case of the other nine steels the measured static energy is from 10% to 20% less.

Yours faithfully,

A. C. VIVIAN.

Finsbury Circus,
London, E.C. 2.
January 19, 1946.

The Editor, METALLURGIA

Sir,

In the letter "Static Tension Energy" from the pen of my namesake, Mr. Vivian of London says he thinks the exponential strain method introduces unnecessary complications, and embarks on a competitive analysis of Warnock and Brennan's experimental figures in defence of A_0/A—1 strain.

I do not quite know why he should have gone out of his way to use an over-complicated logarithmic relationship between stress and strain for this purpose ; it is actually the same, in the end, as the less complicated relationship to which Dr. O'Neill drew attention in recent years, and with which I made considerable progress afterwards. For, Mr. Vivian's $f = s^m$ (with his unusual and embarrassing meanings for the symbols f and s) is nothing but $f_{true}/F_a = (s_{true}/S_a)^m$, which is $f_{true} = (F_a/S_a{}^m) \cdot s_{true}{}^m$ which is $f = k \cdot s^m$ with the normal meanings of f and s.

Mr. Vivian's $s_u \cdot S_a$ is only s at the U.T.S. He says "It follows also that $m = s_u \cdot S_a\ (1 + s_u \cdot S_a)$." This m, in my own simpler language of letters, is just $s/(1+s)$.* But I am sure he does not suggest that the relationship in question is one of his own discoveries. Mr. Vivian's equations are clothed in different and (I think) extraneous symbols as a result of a transposition of the logarithmic stress-strain relationship which seems rather pointless.

I do not think Mr. Vivian can be right in his assumptions of the amount of uniform extension and of "B" in the equations of his actual analysis. At first, I took a dislike to his method there ; afterwards, I recalled to mind that I had made and tested to destruction by tension some specimens identical in shape and material to this one he is dealing with ; and the fact is that they did not have any uniform extension ! So, the whole of the specimen must conform to Mr. Vivian's "B" category.

But, in his paragraph following the equation giving "total stretch," Mr. Vivian begs the whole question. For, at this very point is the "catch." Can we safely follow and weigh the inferences and consequences of mere plausible suggestions in this vital paragraph ! Why should we put our trust in statements the consequences of which are far from clear ? Mr. Vivian has actually endorsed the simpler $f = k \cdot s^m$ by his own use of the more complex but otherwise identical "f" = "s"^{m}, as has already been shown. From $f = k \cdot s^m$, by simply turning the handle of the integration machine, you can have the energy required to fracture unit volume if only you employ exponential strain. It then remains to apply this computation to the number of sections of the tensile test-piece warranted by the amount of change of shape throughout its length after fracture, and by the degree of accuracy required. This, it may be remembered, is what I did† which Mr. Vivian is trying to improve upon by making assumptions only to be described as unwarranted. If he arrives at a figure by analysis comparable with the experimental figure of the joint authors (Warnock and Brennan), I am personally at a loss to understand how this came about.

Yours faithfully,

A. C. VIVIAN.
(Dr. Vivian of Bedford.)

Bedford.
Feb. 6, 1946.

* "An Analysis of Hardness," *Phil. Mag.*, Nov., 1944, p. 775.
s = n/ 1—n (using n instead of m).

† "Fracture, the Sum and Distribution of its Energy," *Engineering*, June 2, 1944 p. 421.

Design Considerations for Welded Machinery Parts

By George L Snyder

Chief Engineer, Lukenweld, Inc. Division of Lukens Steel Company, Coatesville, Pa. U.S.A.

Some basic considerations for the designer in developing weldments are discussed. Separately, they may seem elementary and self-evident, but when considered collectively in developing a weldment, their complexity becomes apparent. At least 12 different types of components can be utilised by a designer in his weldment, and each of these components can be used in several ways. Thus, the designer must be familiar with limitations in processing weldments, and with the scope and limitction of equipment and methods used in their production. These are the factors discussed here, but the discussion, which is substantially abridged, is limited to dynamically-loaded welded machinery parts. Statically-loaded welded structures present another broad subject, and their design concept is decidedly different from thct of dynamicclly-lcaded structures.

HOT rolled steel plate is probably the most universal basic material used for welded structures. Doubtless the freedom offered by the many sizing and shaping possibilities of hot rolled steel plate has much to do with its widespread use for weldment components. Basically, flexible raw material from the standpoint of dimensions, hot rolled plate is obtainable in a very wide range of sizes.

Flat Components

Shearing usually is the most economical methcd cf sizing or shaping a plate to rectangular or circular dimensions. But when a plate is to be sheared to size, the designer should keep in mind the existence of shear drocp, which is the abrupt break in flatness that cccurs arcund the sheared edge because localised stresses impcsed by the shearing pressure exceed the elastic limit of the material. Since this effect is confined to the area adjacent to the edge, it can be practically disregarded when the component is subjected to subsequent trimming, or when it is in light gauges, $\frac{3}{8}$ in. and under.

Flame-cutting is the most common method of shaping and sizing weldment components, particularly when the number cf duplicate weldments required is small. Probably, the main reason for this is the fact that many components of weldments necessarily are irregular in shape.

Since regular configuration generally is cheaper, the designer should think in such terms where possible. However, he need not be concerned if an edge is sheared or flame-cut as long as he designs the part so that the supplier is free to use either method or both cn a particular component.

An example of component prcduced entirely by flame-cutting is shown in Fig. 1, but a combination of shearing and flame-cutting may be employed economically to form parts of a welded structure. In addition to shaping and sizing, the cutting torch also makes welding chamfers, or kerfs, on the edges of a component which provides the "grooves" for welds, other than plain fillets, when assembled with adjoining compcnents.

Tolerances

Tclerance on components, disregarding the methcd used in producing them, merits careful consideration by the des:gner of weldments because an accumulation of tolerances can cause ccstly difficulty in fabrication, as is shown in Fig. 2. This illustrates a highly improbable coincidence of tolerance accumulation, however it could occur within the limits of necessary commercial tolerances on flatness and straightness.

Fig. 1.—Component flame cut to shape from hot-rolled plate.

Often, it is advantageous to size components on machine tools, if only for the reason that much closer tolerances are obtainable. For a complicated assembly with much welding on it, prefabrication machining is indicated. Also, at times, machining of components will help to achieve close tolerance on a complete weldment. The more generous the tolerances on components, the more prevalent the gaps in fitting.

Gaps require the deposition of a greater amount of weld metal, thereby increasing costs and destroying the metal-to-metal contact which resists tendencies to shrink or warp. The main structural parts of the weldment shown in Fig. 3 are pre-machined. Since this item is one of mass production, individual peculiarities in each weldment caused by the non-uniform accumulation of component tolerances could not be allowed.

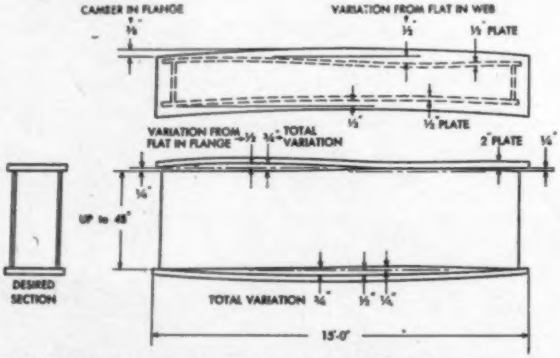


Fig. 2.—Box beam showing camber and flatness tolerance.

Prefabrication Machining

Sometimes design considerations dictate prefabrication machining as in the case of the joint between a heavy web and flange, such as might be a detail of construction on the bed of a large hydraulic or mechanical press. The loading in the region of the compression flange is such that the joint detail shown at the right in Fig. 4, would be necessary if the edge of the web were not machined. When machined, the metal-to-metal bearing, to withstand concentrated compression loads, is achieved. Fillet welds as indicated in this illustration are adequate then for withstanding the horizontal shear components in this region of the beam. The edging of such webs to a relatively close tolerance is a simple operation on a plate planer.

Another reason for prefabrication machining is the provision of economical welding kerfs in combination with good joint fit-up, particularly in welding thickplates. A kerf must provide sufficient width to clear the tip of the welding electrode to permit the depositing of weld metal at the root of the weld. Prefabrication machining is also necessary in instances of conflicting tolerances, in the fitting of circular components within each other. Studies of minimum tolerances reveal that gaps between pieces so fitted are inevitable, but machine fits reduce such gaps to a negligible point. Again, prefabrication machining is necessary at times to enable the provision of proper contours in highly stressed weldments, or in those subject to fatigue. Fig. 5 shows such an instance in the bottom plate of a hydraulic cylinder pre-machined to provide proper curved contour at the corners. This sketch also illustrates an application of machined kerfs on thick plates.

Blanking

Another method frequently used for shaping plate components is " blanking " or " punching " on a power press. This operation which is simply shearing, using knives of special shapes, can be justified, usually, only when quantities required warrant the expense of dies. A simple example of blanking or punching is the shearing of a rectangular plate. By blanking the piece only one operation is required against four operations for each piece in shearing. An important benefit gained by blanking is the comparatively close tolerance which can be achieved.

" Formed " Components

Consideration must also be given to " formed " type components which are frequently required in weldments, for which several methods are in general use. One of these is press bending, to make horizontal angular bends.

Definite reason for forming operations such as bending or flueing have been evolved. One is lower cost, due to the fact that angular bends eliminate one or more welded joints. The cost of bending seldom equals that of the alternative assembly and welding. Careful examination of the design proportions of metal sections might show the economy of using the same metal thickness of web and flange to utilise the advantage of a bent section. A bent component, naturally, is more rigid than a flat one. This can be important in the control of shrinkage and warpage.

Another method, often of value in components, is the specialised forming operation known as flueing, shown in Fig. 6. These flued openings, when machined, provide formed seats for covers. Treatment permitted by the flued opening eliminates assembly, welding and

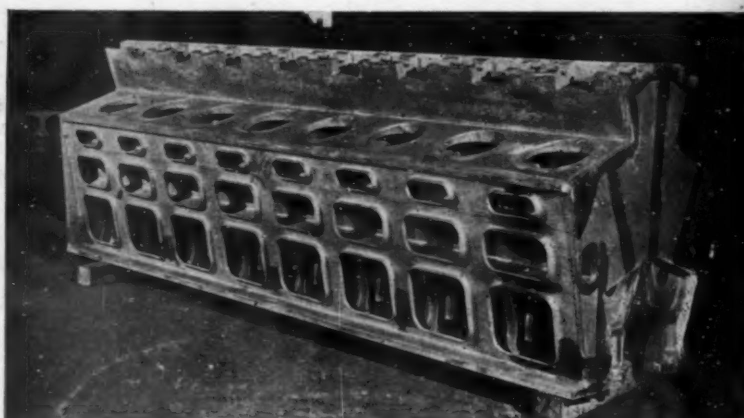


Fig. 3.—16-cylinder " V " type welded Diesel engine frame.

consequent warpage, and the cost of many drilled and tapped holes. Another function of flued openings in weldments is to provide stiffening lips, which are executed normally by welding a band around the opening where required by design considerations.

Since dies are necessary, flued openings are unwarranted economically, unless the quantity of openings justifies their use. When flued openings are being considered, the designer should consult the supplier, for it is possible that dies exist which can be adapted.

Stamping and Pressing

When quantities justify, formed components produced in special shapes by forming dies on power presses, may be used advantageously. Fig. 7 shows a small stamping, four of which form the corners of a water-cooled furnace door. Forming, required on the remaining components, is done on a press brake. Fig. 8 shows the relation of the various components in this weldment.

A useful method of shaping cylindrical contours is provided by bending rolls. Shapes formed on a rolling mill also may be used justifiably in weldments. Their value as components results from two factors: a reduction in cost, because of elimination of welding, and initial rigidity which can tend to simplify fabrication problems of shrinkage and warpage. In considering the use of structural rolled shapes, the tolerances possible in such rolling-mill products should be studied carefully, as they may adversely affect the design requirements.

Steel castings are used extensively as components in weldments where economy in producing complicated-shape requirements or special contours at given points in a particular assembly is involved. When castings are to be used, their physical and chemical properties should be specified carefully. Also, where size permits, it is desirable to have castings of electric-furnace steel, which seems to possess greater cleanliness. This is important in obtaining good welds with minimum difficulty.

Drop forgings also may be used when their size and quantity justify the investment in dies. This product has good homogeneous properties and, when properly controlled, its tolerances are close. Fig. 9 shows such application where a number of drop forgings have been joined by flashwelding.

Fig. 6.—Weldment showing utilisation of flued openings.

Fabrication

Having considered the production and application of components, the subject of fabrication from the designer's viewpoint in developing a weldment is the next consideration. The first aspect covers the type and extent of available equipment in a welding shop which will produce the pieces designed. This is important, since the more flexible and extensive the equipment, the more freedom there is in design. In addition, when quantities are involved, advantage may be gained in designing the job to suit particular facilities.

Production methods concerning the fabrication of weldments may be considered from two aspects. The first involves the extent of what might be termed "universal" equipment, such as positioning facilities, automatic welding units, inspection methods, and stress-relieving facilities. Many types and sizes of positioning equipment are in use in welding shops to-day. The second aspect involves special jigs or fixtures or other types of tooling that might be justified or imperative.

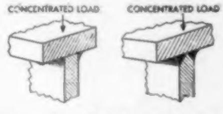


Fig. 4.—Joint between heavy flange and web, showing machined edge (at left) and full weld (at right).

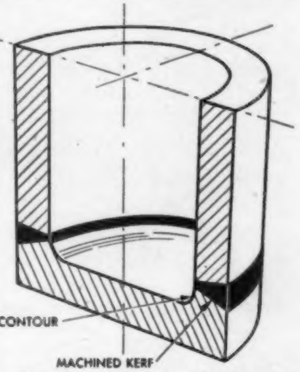


Fig. 5.—Bottom of hydraulic cylinder, typical of those used in heavy hydraulic presses.

Usually, if the product is to any degree repetitive in quantity, the possibilities in special tooling should be considered.

Also to be considered by the designer to promote economy and quality is the possibility of breaking up the weldment into sub-assemblies in sizes to suit positioning equipment. If the final size of the part as designed exceeds the limits of available equipment, possibly it can be redesigned so that a minimum of handling of the piece in its final size is necessary. Often, the use of automatic welding equipment with its finite scope and features merits a thought in designing the weldment, especially in considering the advantage such equipment offers for cost reduction.

With special tooling, the designer should keep in mind that he is dealing still with rough component parts, despite measures that might have been taken to minimise tolerances. Weld-shop tooling, naturally, is more restricted than that usually available in machine shops. Tools, such as jigs or fixtures, should be designed with the necessity of flexibility in mind. Fig. 10 shows a special fixture which is typical. Special tooling also might be mandatory in order to hold components in proper relation to each other during the welding operation.

Sub-Assemblies

Although sub-assemblies frequently are important to the designer of weldments, design limitations often prohibit their use. Obviously, the more work done on small pieces, the easier and quicker will be the completion of the final assembly. A completely welded sub-assembly is shown in Fig. 11; the final weldment is shown in Fig. 12. Here, design controls the methods of fabrication, for the lower flange member could be made in one piece. In that case, at least a portion of the sub-assembly welding would have been required on the larger and more cumbersome piece.

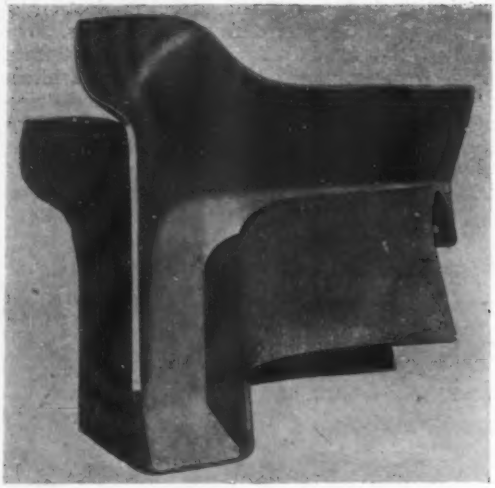


Fig. 7.—Corner stamping of water-cooled furnace door.

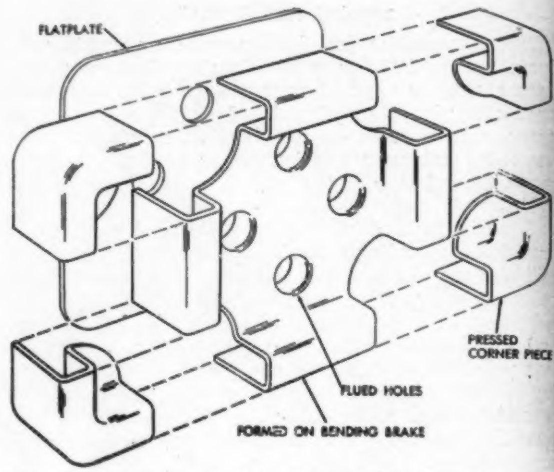


Fig. 8.—Diagram of the water-cooled furnace door, showing construction.

Sub-assemblies of components should be made so that particular portions in certain instances can be sized before they become part of the final weldment. This practice helps to insure that the final weldment is close to required dimensions. Where tolerances have accumulated, straightening or trimming might be involved. The effect of the welding on the completed sub-assembly from the standpoint of warpage or shrinkage has been eliminated as a factor on the finished weldment. Sometimes in very complicated structures involving considerable welding, various sub-assemblies are stress relieved before being assembled into the whole structure to reduce the accumulation of residual stresses.

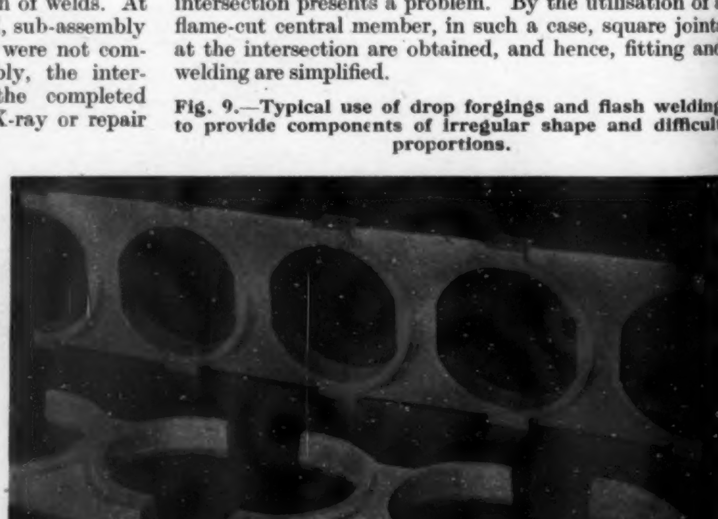
Sub-assemblies also facilitate inspection of welds. At times, where X-ray inspection is specified, sub-assembly welding is necessary, for, if the welding were not completed and X-rayed in the sub-assembly, the interference of adjacent components in the completed assembly might make it impossible to X-ray or repair such welds.

An important reason for careful consideration of sub-assembly possibilties in design is the provision of maximum access for the greatest possible amount of the welding to be done, for the more accessible the welding, the less it will cost. Also, quality is more readily achieved if the welding operator can work under open or accessible conditions. Fig. 13 shows a sub-assembly on which all welding to be done is before the operator. Where maximum access is provided by sub-assembly practice or other design control inspection can be more conclusive. Fig. 12 illustrates design for accessibility with elliptically shaped openings permitting access to the inner side of the joints to be welded. Here, desirable structural qualities of a box member are not sacrificed for access, but care has been taken in shaping the openings so that abrupt discontinuities in the contour of the members are avoided.

Welded joints of maximum quality and predictability from the standpoint of either external contour or internal soundness are almost impossible to execute with the manual arc, if the joint is not reasonably accessible from both sides. However, at certain points where stresses are of secondary nature and fatigue loading is not present in structures, the joints do not require work on both sides.

At times, spoked or diagonal members are indicated by design considerations, and their intersection usually presents a type of joint difficult to fit and costly to weld if proper external contours are to be maintained. For instance, diagonal box stiffeners are frequently desirable on the underside of certain machinery bedplates from the standpoint of maximum rigidity, and their central intersection presents a problem. By the utilisation of a flame-cut central member, in such a case, square joints at the intersection are obtained, and hence, fitting and welding are simplified.

Fig. 9.—Typical use of drop forgings and flash welding to provide components of irregular shape and difficult proportions.



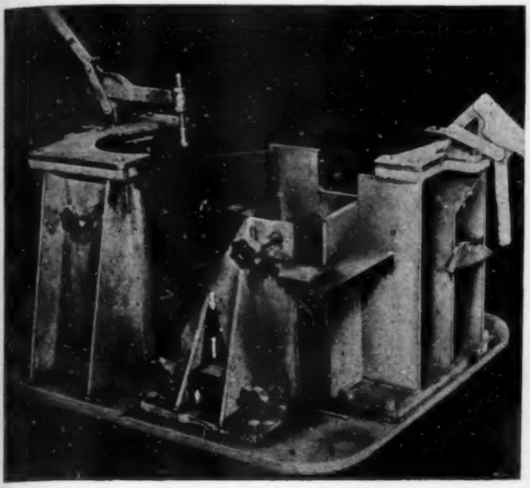


Fig. 10.—A specially designed fixture for tooling weldments in quantity production.

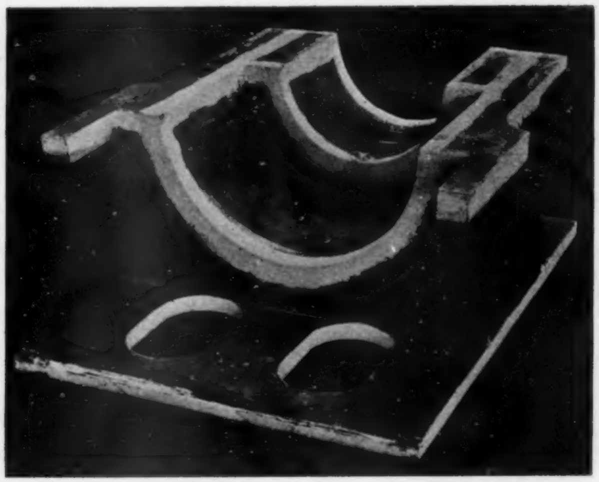


Fig. 11.—A sub-assembled component of a weldment. Welding is completed before further assembly is done.

Shrinkage and Warpage

Shrinkage and warpage problems which exist in the production of weldments will continue to be a factor so long as drastic heat gradients occur during welding. A degree of experience is needed to be able to predict such effects and to control and counteract them. Warpage will occur to a varying extent depending on the relative size of given welds and their distances from the neutral axis of the assembly. This is due simply to the relative ability of a member to resist shrinkage stress imposed at different points in its cross-section with respect to the neutral axis of that cross-section.

Welding results in shrinkage both longitudinally and at right angles to the weld metal. The extent varies for sizes as well as types of welds. When the number of different sizes and types of welds occurring in an average weldment, and their length and position with respect to each other are considered, it can be realised that control of warpage is to a large degree a matter of practical experience. Sequence of welding also should be carefully controlled as a counteracting measure. Sometimes, special fixtures are used to restrain warpage during welding.

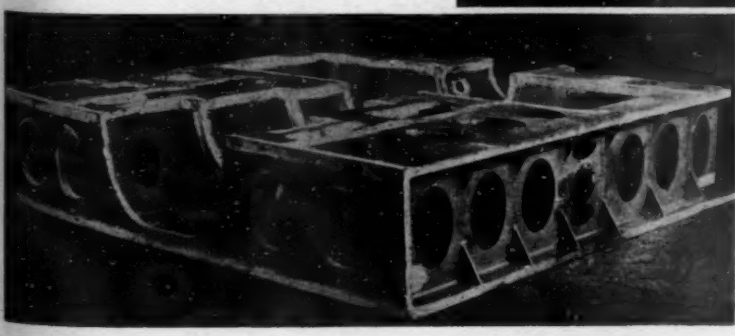


Fig. 12.—Lower section of welded gear-reduction housing.

Conditioning and Inspection Methods

Following completion of welding it is an established practice to condition the weldment by removing spatter, grinding edges or surfaces where specified because of design requirements, and grit blasting when size permits. Spatter is removed for appearance and to insure that it will not drop off progressively when the weldment is in service. Spatter can be detrimental mechanically if, for instance, it were left in a lubricating-oil compartment. Weldments are grit blasted to remove mill scale from plate surfaces, and to facilitate visual inspection of welds. Under-cuts usually are more difficult to detect before the weld is grit blasted.

Fig 13.—Welded sub-assembly, with all welding easily accessible.

Welds are inspected visually for proper size, surface cracks or other surface defects. X-ray is used to inspect welds for internal defects. Various specifications provide inspection standards for the acceptance or rejection of welds by means of X-ray photographs. Hydrostatic testing often is required by design specification. Oil-tight compartments

should be checked and tested before the part leaves the welding shop. Finally, the weldment should be laid out for a final inspection to verify that it is dimensionally correct within specified tolerances.

Any weldment to be machined should be stress relieved if the machined surfaces or other parts of the weldment are to hold their relationship within service life. Any weldment subjected to severe stresses or to fatigue or impact, also, should be stress relieved Especially is this advisable since locked-up stresses, the magnitude or direction of which cannot be predicted can be of a high order following welding. If normal service loading imposes design stresses having the same direction at a given point as that of a residual or locked-up weld stress, structural distress or failure can result.

Many weldments are in use that have not been stress relieved. Hence, definite predictions cannot be made that difficulty will result for a given type of weldment in the unstress-relieved state. Stress relief, therefore, may be regarded somewhat like insurance having a low premium rate because the per-pound cost of stress relieving is usually only a fraction of a cent.

Contributed by the Production Engineering Division and presented at the Annual Meeting, New York, N.Y., November 26 to November 29, 1945, of the American Society of Mechanical Engineers.

Restoration of Steel Plant in Southern U.S.S.R.

By I. Andronov

ANOTHER blast furnace of the Enakievo Iron and Steel Works, of the Donetz Basin, has been restored and put into operation. The Germans had blown up the units of this furnace, almost totally destroyed the furnace, including the inclined skip hoist, and reduced the turbo-blower to ruins. Many months of hard work have been necessary to get this furnace to function again. This is the fourth blast furnace the Enakievo engineers have rebuilt and put into commission. It is just over two years ago, on December 23, 1943, since the first blast furnace was restored and put into operation ; the second followed soon afterwards. Gradually the need for increased production necessitated the restoration of the third furnace, and now the fourth is in operation.

Before the war, fully two-thirds of the iron was produced by the iron and steel works located in the Steppes of the Ukraine, and in areas near the Black Sea coast. It was in these areas that the Germans partially or totally destroyed 62 blast furnaces, 213 open-hearth steel furnaces, batteries of coke ovens totalling 4,740 ovens, with an annual output of 19 million tons of coke and 248 rolling mills.

Including the furnace just put into commission at the Enakievo works, there are now 18 restored blast furnaces operating in the southern part of U.S.S.R. More than 70 open-hearth furnaces are now engaged in the production of steel, 50 rolling mills are functioning and many blooming mills, Bessemer converters, coke oven batteries, etc..

Production at some of the iron and steel works has already reached the pre-war level. No. 6 blast furnace of the Dzerzhinsky Works has even exceeded its pre-war output. At the neighbouring Petrovsky Works pig-iron output has increased sixfold since the beginning of last year, and steel production more than four times in the same period. The output of the Lenin Dniepropetrovsk Works is approaching its pre-war level ; some of the rolling mills, by adopting an improved technique, have already passed their pre-war output.

The demand for iron and steel is growing continuously. Restored and newly built machine-building plants want more high-grade steels for the production of consumer goods, beams and girders are necessary for building construction, pipes and tubes are needed for water, gas and oil, and the restoration of road and rail transport is making big demands on the industry. Special grade steels will soon be wanted by the Dniepropetrovsk motor-vehicle and compression-engine assembly plants now under construction in the Ukraine. Agricultural machinery is also reviving ; the Kharkov Tractor Plant will soon be functioning, and so will the shipbuilding yards at Kramatorsk, Voroshilovgrad, Nikolaev and Zaporozhye.

The growing demand for iron and steel has necessitated the rehabilitation of iron and steel plant to be speeded up with the result that the works in the Stalino region have already restored nine blast furnaces, 18 open-hearth furnaces, 47 coke oven batteries and three Bessemer converters. It is expected that, early this year, five more blast furnaces, nine open-hearth furnaces, 15 rolling mills and 10 coke oven batteries, which were near completion at the time of writing, will be in operation. It is noteworthy also that by the end of 1945 the Dniepropetrovsk region had six blast furnaces, 26 open-hearth furnaces, 26 rolling and tube mills, 54 iron-ore mines and 10 manganese-ore mines operating, and the manganese-ore mines were giving double the output of pre-war years.

Additional open-hearth furnaces and rolling mills being installed at Makeyevka are nearing completion. The third blast furnace will soon be blown in at the Voroshilov Works, at Alchevsk ; at the Konstantinovka Works the second blast furnace is about to be put into operation, and restoration of the iron and steel works at Zaporozhye and at Kerch are well under way. Soviet metallurgists and iron and steel plant engineers are making great efforts to heal the scars inflicted on their industry, and to restore the pre-war output of the iron and steel works in the south of the Soviet Union, and their efforts are exceeding expectations.

X-Ray Analysis Conference

THE X-Ray Analysis Group of the Institute of Physics announces that by the kind permission of the managers, its 1946 Conference will take place at the Royal Institution, London, on July 9, 10 and 11 next, and is open to all without charge. It is hoped that several distinguished foreign scientists will participate in the proceedings. Accommodation in London is very limited, and those proposing to attend the Conference are advised to make reservation immediately.

Further information will shortly be available from the Honorary Secretary, Mr. F. A. Bannister, F.Inst.P., Department of Mineralogy, British Museum (Natural History), Cromwell Road, S.W. 7.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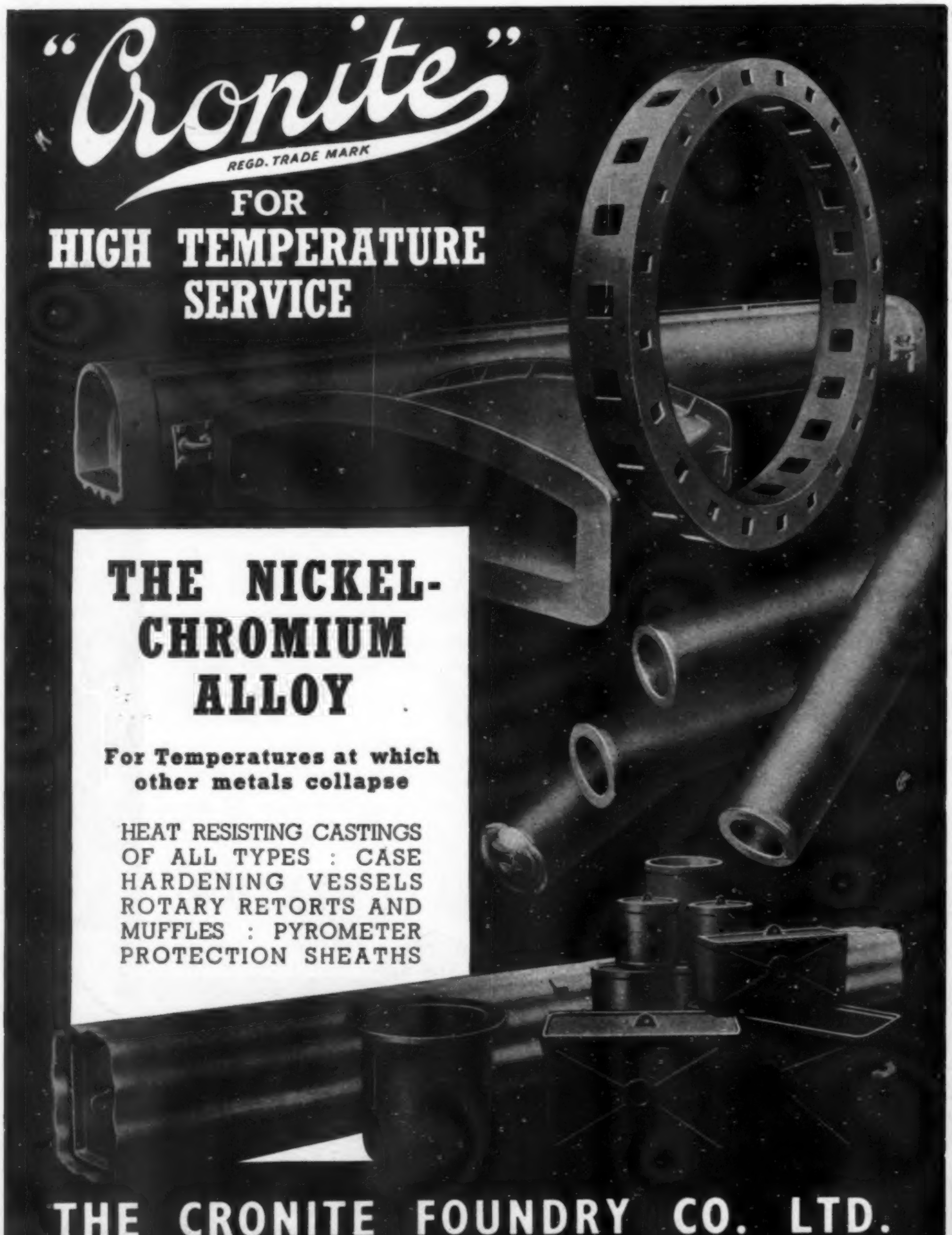

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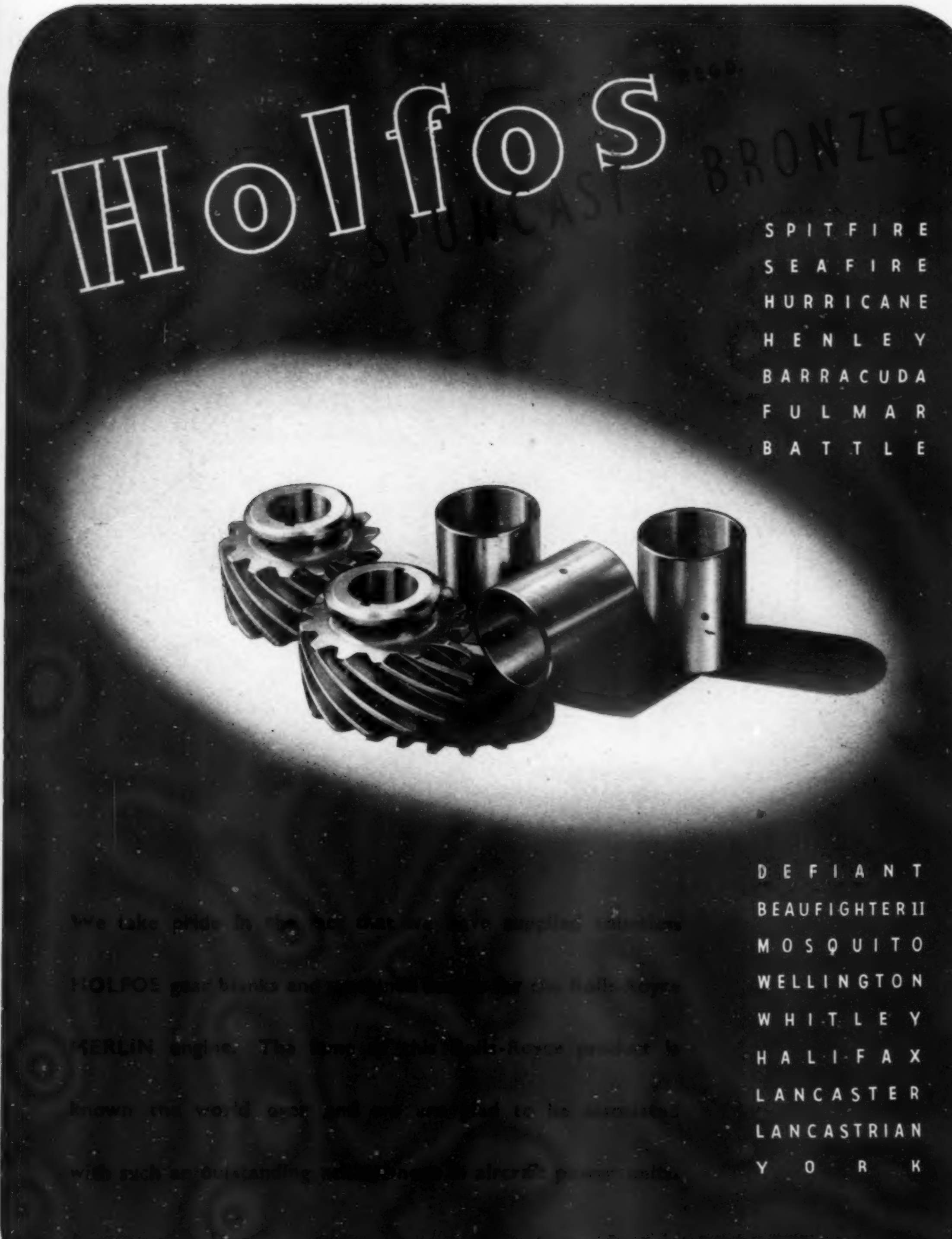
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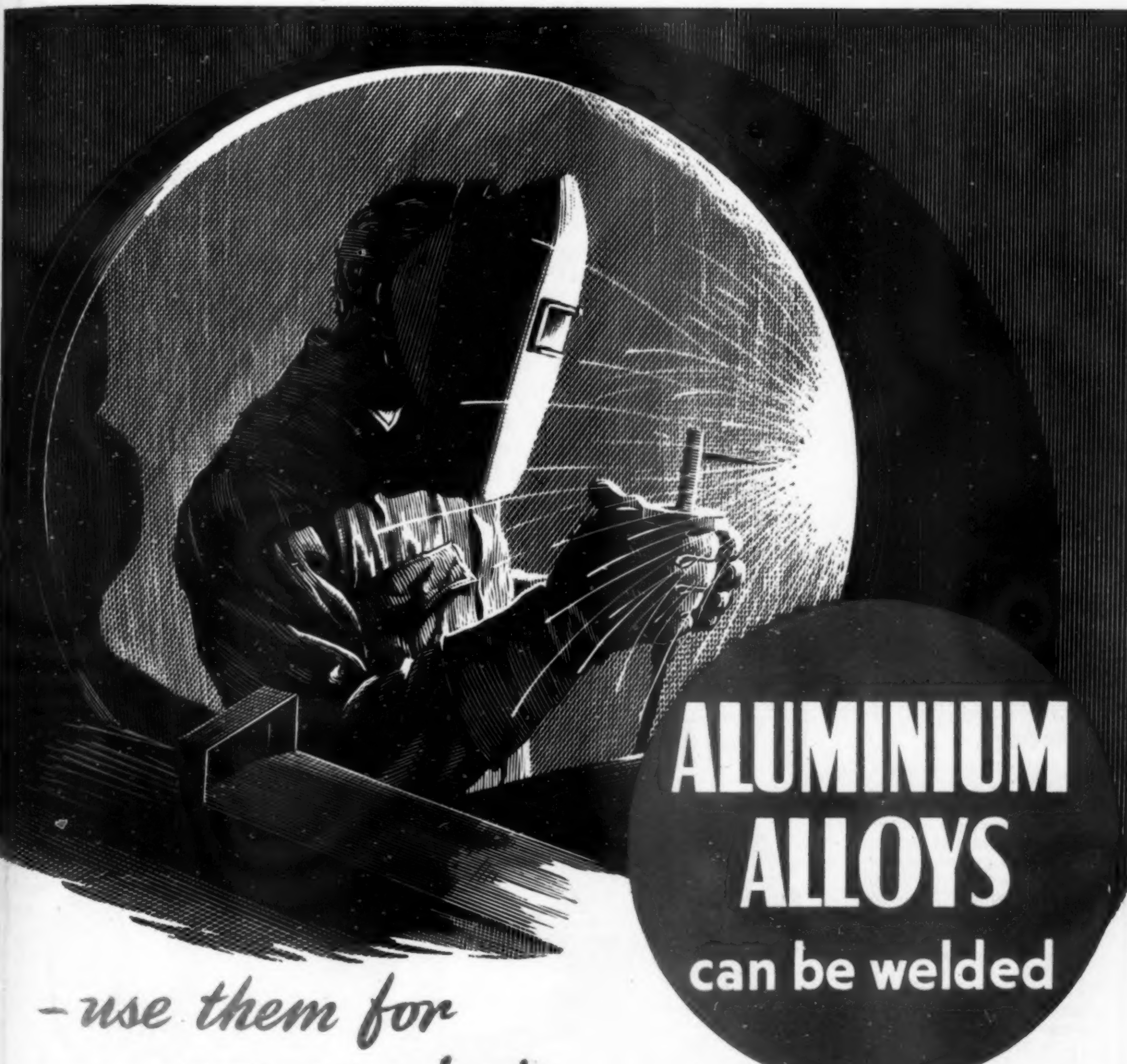


– use them for your projects

MANIFEST are the advantages of aluminium and its alloys — it is ductile, resistant to corrosion, free from rust, has excellent strength/weight ratio, is fine in appearance — and to these can be added its ability to be welded by both fusion and resistance processes.

There have been misconceptions about welding aluminium alloys — misconceptions based upon established practice in welding. But, now, research has found a way of meeting the problems of welding aluminium, of devising and providing oxide destroying fluxes, of temperature control, of operating methods departing from conventional practice but which on aluminium alloys give strong, perfect welds.

If, then, your product is one which necessitates welding, but would also gain from lightness, strength, ductility, freedom from rust, and good appearance, then aluminium or aluminium alloys are indicated. In The Aluminium Development Association's Information Bulletins Nos. 5 and 6 — free on application — the subject of Aluminium Welding by the various processes is clearly and exhaustively described.

THE ALUMINIUM DEVELOPMENT ASSOCIATION

SIXTY SEVEN, BROOK STREET, LONDON, W.1

Aluminium and the Building Programme

By GEORGE MORTIMER

The need for dwelling houses and the scarcity of building materials and labour have directed attention to the possibility of aluminium helping to meet the need, and the author shows how the Nation's aluminium reserves can be effectively used. It should be remembered that the employment of aluminium in building is not new, its application in this industry was growing rapidly for a decade prior to the war. While its use in construction was confined mostly to large offices, stores and public buildings, it was also being used for dwelling houses and other structures, and included a wide variety of applications. In the present emergency real expansion in the uses of aluminium for building lies in a plentiful supply of all building assemblies and hardware in aluminium, through the normal channels, in forms which the builders can use.

Church spire in Pittsburgh in cast aluminium.

OF all the manifold domestic problems left us by the war, none is more urgent than that of building. Destroyed and damaged buildings must be made good: large dwellings converted to flats: the leeway of six lost years of normal expansion made up. Figures have been published and broadcast, and there is no need to recount them here. It is generally recognised that this one job of work will call for all the organising ability, courage and imagination the nation showed in winning the war itself.

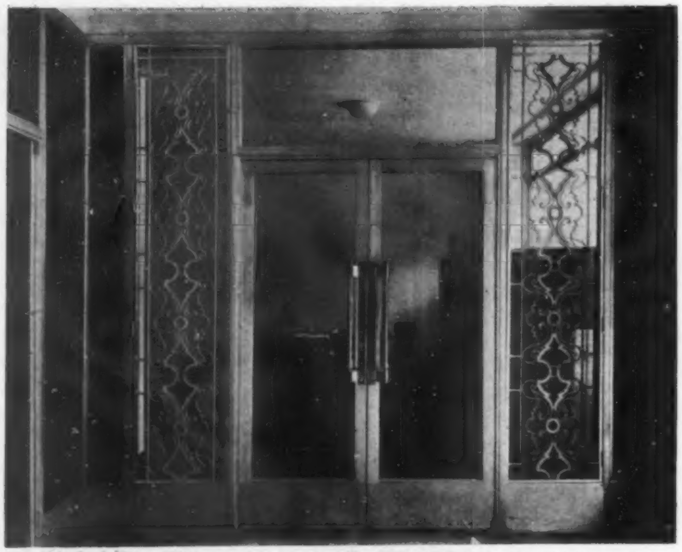
Alongside this national problem lies another. The need for huge outputs of planes ceased with peace. The sluices have come down on that great river of aluminium which fed our square miles of factories. Large tonnages of the metal lie in stocks and process, in refined alloy scrap, and in material continually accruing from obsolescent war equipment. Some significant part of the million or so skilled workers in aluminium must be found peace-time employment in the material they understand, or be trained anew.

Aluminium can Span Transitional Period

After the last war we experienced a sort of proto-type of the difficulties we now face, but this differed in scale and also in one significant point. Building labour was limited, but was on the whole reasonably adequate for the task, which lacked the present extreme urgency. Building materials were in fair supply for the job in hand, and there was no notable surplus of aluminium, or of labour trained almost exclusively in its forming and handling. The position to-day is practically the reverse. Aluminium is one of the few materials available in ample supply, whilst many other suitable materials would need to be purchased abroad, and paid for, and transported to these shores in ships urgently needed on other work. A large pool of labour, skilled in the fabrication, forming and finishing of aluminium is available together with modern factories largely lying idle, whilst much of our building labour perforce remains on garrison duty all over the globe. This one factor of "availability" is in fact the keystone of any broad building plan, conceived with an eye to national economy. It is difficult to picture any Government granting extensive permits to purchase materials abroad, if suitable substitutes lie fallow at our feet.

There is, of course, nothing novel in the employment of aluminium in building. All over the world the metal has been coming into extensive use for at least a quarter of a century, for roofing, glazing, insulation, external embellishment and internal trim. One New York building alone uses 1,200 tons of aluminium spandrels to cut weight on the foundations. A church in Pittsburgh possesses an aluminium spire. Architects in this country have come to realise two attributes of aluminium additional to the obvious one of lightness: resistance to corrosion, and an appearance which conforms to modern ideas on decoration. A large and increasing tonnage goes into buildings in some form or other throughout the world. It is mainly in the decorative field, in grilles, shop fronts, staircases, escalators, etc., that this metal has made most appeal in this country to date; but this is due to the factor of relative availability referred to above. Given adequate supplies of aluminium and shortages of certain other building materials, no technical obstacle stands in the path of a far wider use of the light metal.

That this is recognised, is seen in the Government sponsorship of the A.I.R.O.H. Aluminium House, one of the more attractive of the many prefabricated bungalows, and a job which reflects much credit on those responsible for its design and development. In the present emergency prefabrication has much to commend it, whether the material be aluminium, steel, concrete or timber. Labour on site is reduced to the minimum, that is, the type of labour least available at present. The bulk of the work is transferred to otherwise redundant factories, where it is independent of that builders' bug-bear, the weather. This little A.I.R.O.H. dwelling



This "Aladdin's Lamp" aspect of aluminium is a side-door of the main entrance to Arlington House.

is excellently planned for domestic labour saving: it is warm and dry, and unexpectedly quiet and solid, a very useful contribution to the immediate needs of the community. It is, of course, more like a bijou flat or the interior of a luxury yacht than pre-war ideas of a house, but it seems likely to prove anything but temporary. However, there are Dominions and Colonies which, later on, may well be glad of numbers of so portable a bungalow, if only because the design will keep heat out as well as in, and the material would break the heart of pests such as the white ant.

The factory production of bungalows, however, is a measure of first-aid only, aiming to span a difficult transitional period. What part can aluminium play in the nation-wide schemes for permanent houses, built by traditional methods, or in the conversion of too-commodious dwellings to more or less modern flats?

Here we have a wealth of light, strong alloys, most amenable to forming and assembly, not readily corroded nor stained, reasonably cheap and very plentiful in a country of shortages. They are capable of taking some of the finest finishes this civilisation has yet seen, and heavy albums of photographs testify the splendour of banks and institutes and airports, and so on, which have been enriched by exquisite application of alloyed aluminium and the finishes it offers.

Speed calls for Prefabrication

In our own domestic problem, however, we are less concerned with this Aladdin's-lamp aspect of aluminium than with the relatively humble needs of the man in the street, the returned Service man, the newly married couple. Speed is essential, and speed implies a wider use of the factory production line, an extension of the "prefabrication" which builders themselves have been accustomed to for years. If standard windows and doors can be delivered to site, as they are, ready for erection, so can whole plumbing assemblies, gas and electric circuits, staircases, partitions, sections of roofing and flooring, kitchenettes, cupboards, pelmets and curtain rails, internal trim and external garden and cycle sheds, etc. It is here that aluminium, with its background of huge modern factories and skilled personnel, its proved suitability and plentiful reserve, can make the most telling contribution.

Each A.I.R.O.H. house has seven windows, an attractive and obviously sound application of aluminium alloy, whether cast or wrought. About 350,000 of these light, rot-proof windows will be needed for the present programme of the A.I.R.O.H. house. But, at least, 3,000,000 could be taken up by the first year's target for new houses of the permanent type, if these windows were obtainable in such quantities. The same remarks apply to a certain extent to the myriads of doors needed; some of the composite designs employing aluminium are an asset to any house, and they save timber.

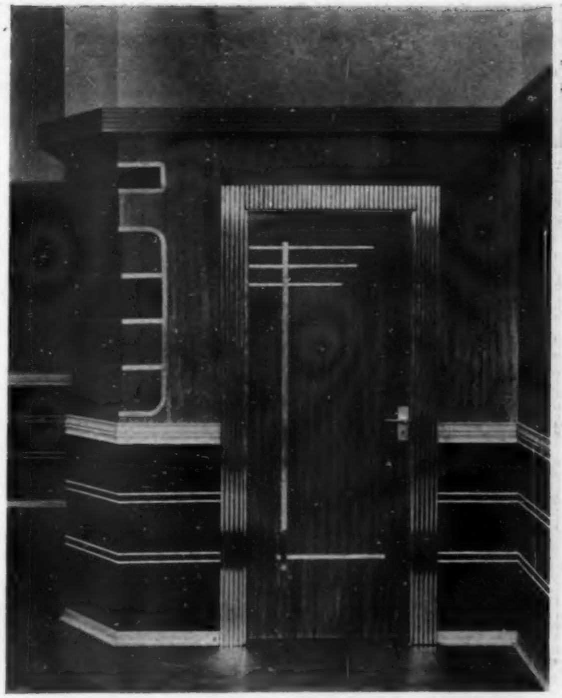
The standard plumbing assemblies receiving official encouragement offer no obstacle to aluminium as far as ease of fabrication goes; but this is not one of the applications the author can whole-heartedly recommend at this stage. It is true that aluminium is one of the common metals most resistant to corrosion, and if a few white spots appear on a window frame, a wipe with a duster will remove them. If local conditions are such as to encourage corrosion, as for example, continual subjection to sea spray, then there are protective methods as in the case of steel or timber window frames. They may be painted, or sprayed with a modern synthetic lacquer, or oxidised by dipping or anodising. Conditions within a domestic water system, however, are complicated by variations in the nature of domestic water from one district to another, the presence of other metals in the system to which aluminium may be electro-positive, and the effect of certain water-softening processes. Protective measures are not readily applied with certainty to the interior of a congeries of tubes and valves, and until research has established the effects

An air-conditioning grille in aluminium alloy which conforms to modern ideas on decoration.

of the above factors the normal materials will continue in use for this component. That research is proceeding in laboratories and in practice, and in the meantime no such reserve attaches to prefabricated assemblies for gas and electricity services.

Possible Aluminium Components

One component which takes much timber seems seldom considered in connection with the light alloys. Any large-scale scheme must necessarily standardise as many components as practicable, and this would surely include the staircase. The strong alloys of aluminium would be ideal here, and a competition for the design to be accepted as standard would focus interest. Such a staircase would be permanent, silent and fireproof: designed by an architect, it could be a thing of dignity and beauty, giving tone to the whole house. Roofing shingles and tiles have been widely used in the States for many years, and in this country they have been formed in large sheets, easily transported and erected. Roof and floor members in light alloy present no difficulty, and would save a wealth of timber. Even in traditionally-built brick houses there are particular features, such as upper and lower bay-window elements, which lend themselves to fabrication in light alloy, ready for delivery complete to site. From chimney-pot to damp course the ordinary builder can employ aluminium in all sorts of directions without worry; chimney-pots themselves, chimney-base rings, ventilators, gutters and gutter ends. These and many other items of builders' hardware not only can be made, but are being made and supplied now in aluminium alloy. The conversion of tall Victorian residences to flats entails the provision of kitchens and offices on each floor, and here aluminium comes into its own in the excellent "package" unit kitchen equipment now available in several forms, which not only provides everything necessary in a kitchen in compact form, but reduces the cumulative weight of several kitchens, one above the other, to safe limits for old floors and walls.



Modern effects with economy of material.

A small staircase in which aluminium is effectively used.

Most modern architects know these things, and many apply their knowledge: otherwise, we should not have these monumental albums of photographs and technical reports of aluminium in architecture. Many builders, also, have a hazy idea that there is a lot of "Ali" about, and that a good deal of it could be used by them if available in the form in which they can use it. A surplus of alloy ingots means nothing to a builder: he must be able to ring up his usual merchant and get much of his materials and components off the shelf, whatever they are made of. If the light alloys are to be used by the building industry in anything but penny numbers, they must be made available via the usual channels, and in forms with which the builder is familiar.

Since the Aluminium Exhibition at Messrs. Selfridges last year, the author has been approached by groups of builders and builders' merchants anxious to obtain large quantities of two exhibits only—a light-alloy sink and draining board, and windows as seen in the A.I.R.O.H. house. Both were cast, and since the visitors expressed the opinion that the actual makers could not handle the numbers needed, the address of the Light Metal Founders' Association was given. That Association represents the bulk of an industry which has expanded five-fold during the war, and still the enquirers felt that the industry itself could not handle the quantities required. Whether this is through being too busy on

"The Window of the future" die-cast in aluminium alloy.

other things or not, the fact remains that there is some sort of impression in the building and allied industries that the great light metal trades of this country cannot, in practice, help them much when it comes to the big contracts.

Vital Question of Supply

About a year ago the Building Industry came together with the Supply Associations to form the "Building Industries Standing Committee." That Committee started a competition for the best designs for small houses built by traditional methods, as an answer to prefabrication. Thirty pairs of houses were to be built to successful designs, suited to the districts in which they were to be built. Each house must conform to standards of materials and workmanship set by the National Council of Registered House Builders, and should not cost more than £900. The scheme went through with commendable rapidity; plans were submitted and judged, and the first two pairs of exceptionally "eyeable" houses were officially opened near London, in January. For these prototypes the builders obtained materials permits for normal materials without undue difficulty. But, if these pleasant little homes prove as popular as they well may, the materials allocation for, say, 100,000 houses is rather a different proposition to that of 60 prototypes. It is then that the availability of substitutes will arise in an acute form, and it is by then that the light metals should be available in forms in which they can be used by ordinary builders. The ability of the aluminium industry, together with the huge allied aircraft industries, to supply building components in large numbers need not be called in question.

The alloys used in building, cast or wrought, are now well known. With the pure metal they are supplied subject to strict specifications accepted by British Standards Institution, and it is not intended here to repeat the prolific data given in the technical press during the past few years. If a builder or his supplier really wants to know something about the analysis and properties of yellow brass or stainless steel, or the specification for timber floor joists, he reaches for a handbook on the subject. Aluminium has long settled down to the same status, as a common or garden material for the ordinary man to do a job of work with. The Aluminium Development Association, 67, Brook Street, London, W. 1, issues concise and accurate data on all aspects of these light materials in a handy form for reference, and can also give practical guidance on design of buildings components and assemblies, the alloys to use and how to use them. Enquirers can be brought in contact with actual makers. Difficulties, imagined or real, can be sorted out by men who know the answers.

But, whilst the spreading of technical knowledge is the only sure education on the long view, it is also slow, and the present position calls for speed. Manufacturers know the basic facts, or they would not successfully be manufacturing. They will always be interested in any new established facts, on developments such as plastic bonding of the Redux type, synthetic lacquers which will give attractive and permanent finishes without the present bottleneck of anodising, any new alloy which does the work and costs a fraction less, any applied pattern to sheet and strip such as Imprestal, in fact, any line of development which may cheapen processing or offer a more saleable product. But, manufacturers in this country, as a whole, have their basic facts pretty well understood.

There is only one royal road, in the present building emergency, to the real expansion of the uses of aluminium in ordinary building. That lies in a plentiful supply of all building assemblies and hardware in aluminium, via the normal channels, in forms which the builder can use without studying scientific theses, from roof-truss assemblies to the humble wood screw. Builders themselves will continue to ring up their usual suppliers for batches of this or that, and provided these conform to standards set by Local Authorities, price and prompt delivery are the points he is concerned with. If, through co-operative effort, the present needs of the building trades can be met from the nation's aluminium reserves to any substantial extent, the development will acquire its own momentum, and aluminium will be established as a normal material for ordinary domestic house building and decoration, for all time, on its own merits.

The Institute of Metals

THE annual general meeting of the above Institute will be held at the Institution of Civil Engineers, Great George Street, London, S.W.1, on Wednesday and Thursday, March 13 and 14, 1946. Following the official business and the announcement of the award of the Institute of Metals Platinum Medal to Lieut.-Col. Sir John Greenly, K.C.M.G., C.B.E., M.A., Col. P. G. J. Gueterbock, C.B., D.S.O., M.C., T.D., M.A., will be inducted as president. Several papers will be presented for discussion at this meeting and at 7-30 p.m. on March 13, a supper-dance will be held at 4, Grosvenor Gardens, the offices of the Institute.

Developments in the Manipulation of Aluminium Alloys

By R. WORSDALE

A brief account is given of some of the developments achieved in the manipulation of aluminium alloys. Improved technique has shown that production problems, which had previously defied solution, have been overcome and the manipulation processes, primarily developed to solve production problems for war purposes, are now being applied to peacetime products. While the manipulation of tube is given special consideration, it should not be overlooked that the processes developed apply also to extruded bars and sections. Further, investigations are proceeding to continue developments in this field, so that aluminium alloys may be applied to meet the increasing needs of the various industries.

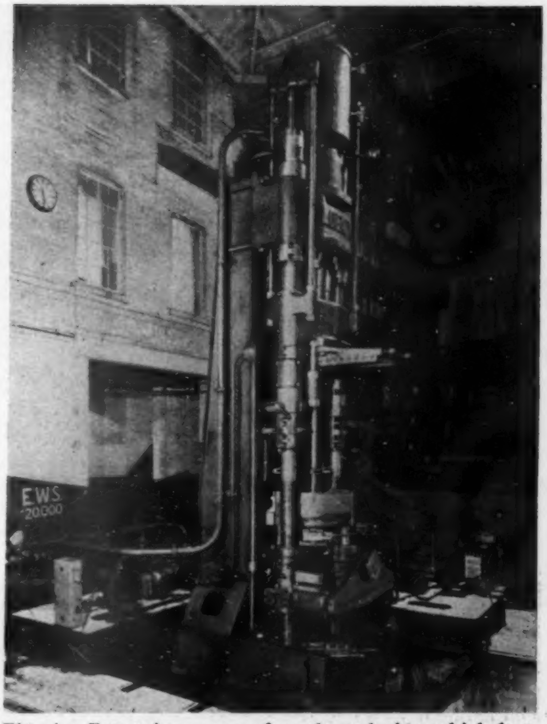


Fig. 1.—Extrusion press of modern design which has contributed to developments in shaping aluminium alloys.

THE expression, "Necessity is the mother of invention," was never truer than during the war years. Under the impetus imposed by our plight after Dunkirk, in 1940, many and varied were the expedients adopted to speed up the provisioning of munitions of war. It is the purpose of this article to give some indication of the results achieved from researches into the manipulation of aluminium alloys which helped to solve some of the many difficulties encountered.

As in most industries, the war brought many shortages to light—not the least among them being manufacturing equipment and metal. Therefore, the utmost economy in metal coupled with the constant urge for increased production produced many difficulties which, at first, appeared insuperable.

Fortunately, the aluminium industry possessed men with initiative. Initially, research was undertaken to improve certain processes in the production of tubes, in which considerable success was achieved — production being greatly facilitated as a result. These researches, however, indicated that the methods adopted had much wider and more general application, in that it was found that aluminium-alloy materials could be manipulated into a variety of semi-finished or finished components not hitherto considered practical or possible. Equipment of special design was indicated, if the utmost benefit was to be gained from the processes developed, and much plant was installed and utilised for the war effort. Fig. 1 shows the type of plant installed (there is as much below ground level as is shown in the illustration.) Unfortunately, difficulties in obtaining delivery of the requisite plant delayed its installation which resulted in some of it not being available in time to be of major use during the war. Details of the processes developed were placed on the secret list, making it difficult to disseminate information to possible users. Now the restrictions are removed, it is possible to indicate broadly some of the results obtained, and their wartime applications. One problem solved concerned the production in quantity of

Fig. 2.—Gas cylinder and sphere in aluminium alloy for high pressures. Note also developments in plate manipulation.

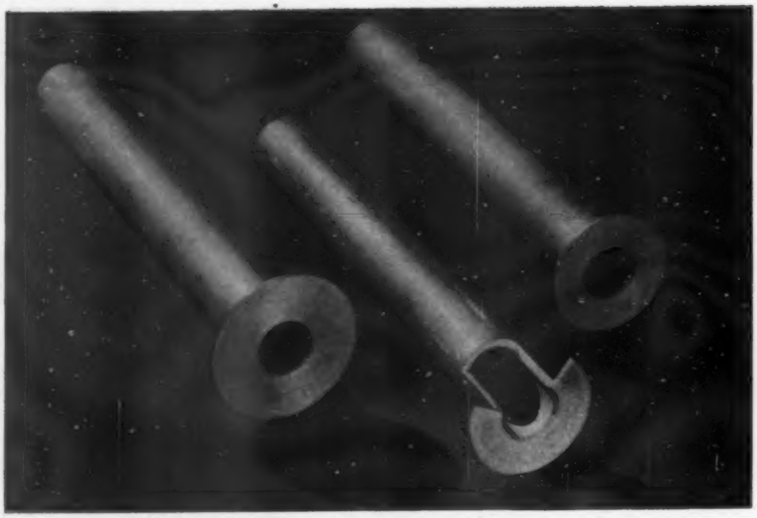


Fig. 3.—Flanges formed integral with the tube.

Fig. 4.—Flanges of various shapes formed with the tube.

gas cylinders and spheres capable of withstanding high pressures. Fig. 2 (bottom, left) shows a cylinder, and (bottom, right) a sphere. This particular sphere had to withstand a test pressure of 3,000 lb./sq. in., and had to be made to fine overall limits, since it had to fit into a very limited space. Its diameter is $6\frac{1}{2}$ in. Excluding the machining and screwing at the neck, this sphere is produced in only four operations from plate. The other two items in this illustration are laboratory examples of plate manipulation.

Frequently, flanged tubes are required—the flanges being of considerable diameter. Hitherto there has been no practical method of producing such parts in any material, but they are now obtainable in light alloy by this new process. By one of these processes, flanges of considerable dimensions can be formed integral with the tube (Fig. 3). If need be the flange can be produced in various shapes (Fig. 4). Furthermore, a sharp corner can be formed where the flange joins the tube, which is impossible to achieve by the other methods (Fig. 5).

Tubes are frequently required to be expanded and/or reduced in diameter. Such operations are well within the scope of this process. Fig. 6 shows two examples. The smaller picture is an experimental flash eliminator, and is an example of expanding and reducing. The larger picture shows expanding at either end to different dimensions: the tube in this instance being $2\frac{3}{4}$ in. o/d. $\times$ 19 gauge expanded to 4 in. at the larger end, and $3\frac{1}{2}$ in. at the smaller end. The tube in this instance being for an artificial limb body. It is particularly pointed out here that in these operations the wall thickness of the tube is not greatly reduced—a very important advantage, particularly for artificial limbs. But the wall thickness can in fact be increased if necessary. One aspect of this process (not illustrated) enables the ends of tubes to be reduced in diameter, but still retain the cross-sectional area of the original tube, or even to be increased; by ordinary tapering methods the reduced ends are always less in cross-sectional area.

Fig. 5.—The process developed enables sharp corners to be formed between flange and tube.

The operation of "butting" tubes, whereby they are increased slightly in wall thickness at one or both ends of a given tube has long been practised. But where both ends are required thickened—*i.e.*, "double butted," the difference in wall thickness has previously been limited to not more than two standard gauge thicknesses. One of these new processes developed enables "double butting" of tubes to an almost unlimited extent. For instance, the examples in Fig. 7 (four right-hand examples) show increases in end-wall thickness three to four times greater than the centre portions. It will be noted that the butting can be on the inside or outside of the tube, and can be of varying length. Butted tubes similar to those illustrated here can be used for a variety of purposes, particularly in applications where screwed end fittings are necessary, the mass of metal available enables the ends to be threaded without weakening the tube in any way. The illustration on the extreme left of Fig. 7 shows an example of a combination of upsetting and butting, the initial tube being only 17 G (0·056 in.) thick before processing.

Special end-forming is another of the processes available, and two types are illustrated in Fig. 8. The two examples on the left show steel inserts rigidly fixed into aluminium-alloy tubes, the completed unit formed a bracing strut in a recently-designed aircraft. This method enables steel and aluminium to be used in conjunction without any fear of electrolytic action, as the union of the two metals is such that entry of moisture is virtually impossible. The two right-hand illustrations (Fig. 8) show a type of end-forming useful for applications for tubes used as rollers where bearings have to be fitted at the ends, such as are required in textile, paper-making machinery and light-weight conveyors. Final examples of tube manipulation are indicated in Fig. 9. Noteworthy in this group are beading inside and outside (top left) and tubes turned "inside out"

Fig. 7.—Examples of "butting" tube providing for increased wall thickness are shown on the right, while on the extreme left is shown a combination of upsetting and butting.

Fig. 8.—Special end-forming processes permit the use of inserts, shown in examples on the left, and for shaping tube to carry bearings, as shown on the right.

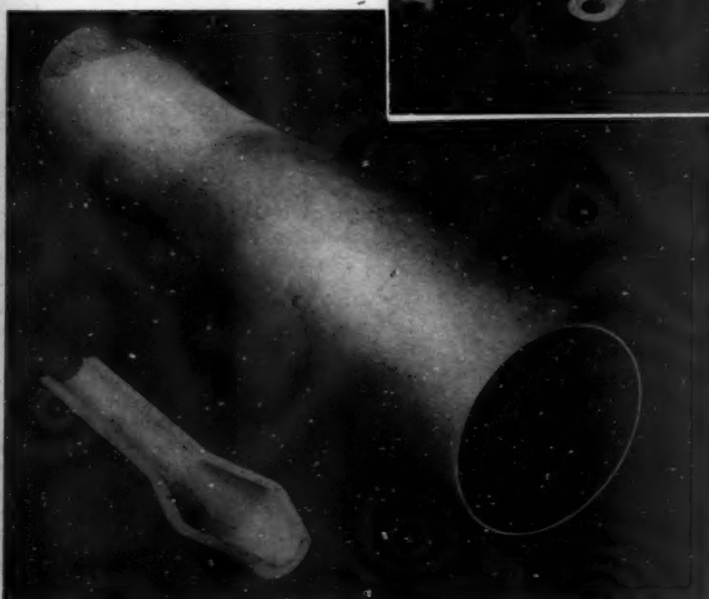


Fig. 6.—Tubes expanded and reduced in diameter by improved technique.

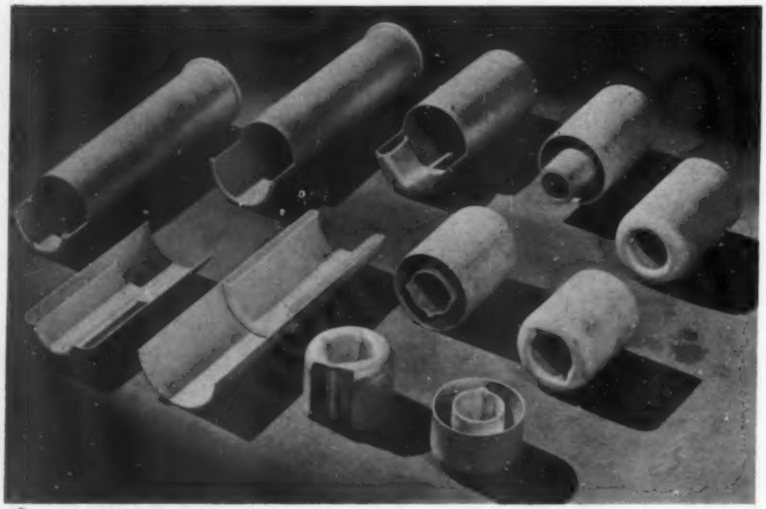


Fig. 9.—Some noteworthy examples of tube manipulation.

and "outside in"—and especially the top-centre picture showing a tube turned inside, and squared in the process.

In case it should be thought that the components described are applicable only to tube and sheet, developments are in progress for their application to bars and extruded sections. These show definite promise of being as universal in their application as those so far developed for tubes. Fig. 5 (centre) and Fig. 10 (top, right) show two examples. The former is an extruded channel which has been thickened at the end to approximately twice its original thickness. In Fig. 10 the process has been utilised to increase the cross-sectional area, while maintaining the original thickness. This process can also be applied to tubes, as well as sections, as the illustrations show. One important feature being that the increase in area can be placed at any point along the length of a tube or section. In the case of tubes, the increase in area is effected without any puckers or folds in the bore of the tube, which would be present with such large increase in area obtained by other methods. The macro-photograph (Fig. 11) plainly shows the metal flow is most satisfactory.

One important point in connection with these new manipulative processes, not to be overlooked, is that of economics. Some of the examples illustrated may appear complicated, and therefore expensive to produce, particularly as regards tooling. This is far from being the case. As an example of the reduction in cost can be quoted the flanged tube (Fig. 10, top, left). This tube produced complete to close limits as shown, cost considerably less than the solid bar from which it had been produced previously by machining.

From the foregoing, it will be appreciated that new processes of light-alloy manipulation are still being developed. Within the ambit of this short article, it is only possible to touch on the many applications which are made possible as a result of these developments, particularly combinations of several processes. By their use, design and production problems will be facilitated, and others overcome which have hitherto defied solution. Still further avenues for the use of light metals will be opened, particularly as similar processes are not possible with other non-ferrous or ferrous materials.

The illustrations used in this article are reproduced by the courtesy of Reynolds Tube Company Limited.

Fig. 11.—Macro-photograph showing that the process produces a satisfactory metal flow.

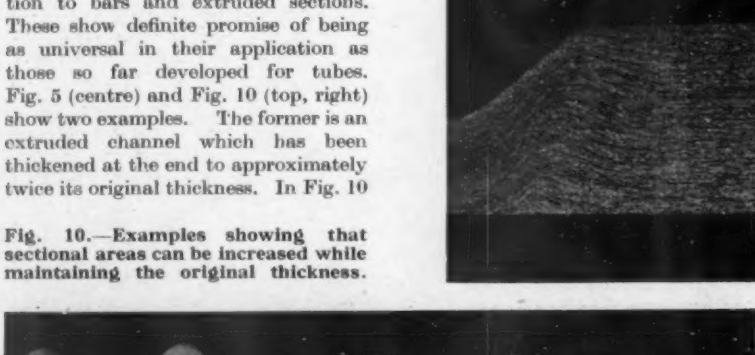


Fig. 10.—Examples showing that sectional areas can be increased while maintaining the original thickness.

The "E" Type Test Piece

"A Communication from the Technical Department of The Northern Aluminium Co. Ltd., Castings and Forgings Division, Birmingham."

Its Development with Reference to D.T.D. 300 and the Lancaster Undercarriage Support Beam

The successful application of aluminium and its alloys to the manufacture of engineering parts involves the recognition of the specialised technique involved in their fabrication and the characteristic properties associated with this class of materials. This is especially true of the aluminium-magnesium alloy, containing nominally 10% magnesium, which has remarkable tensile properties and high resistance to corrosion. Probably its greatest characteristic is its resistance to shock loading, but its use for components in which stresses of this type are encountered involves high quality castings and efforts have been made to develop a satisfactory type of test piece which would indicate, with reasonable accuracy, the important characteristics required of the metal to satisfy specifications. Here, the development of the " E " type test piece is described, with accompanying data.

Introduction

NA 350 (DTD 300) is a high purity aluminium base magnesium alloy which contains nominally 10% magnesium. As raw material for the manufacture of castings it is rather difficult to handle and a high degree of metallurgical control is essential to its successful production. It possesses remarkable tensile properties, extraordinary resistance to corrosion and is somewhat lighter than most aluminium alloys, since it contains no heavy metals. Its greatest characteristic is probably resistance to shock loading and its suitability where stresses of this type are encountered, is sufficient justification for the effort required to produce high quality castings in this admittedly difficult material.

The alloy has been used by the Northern Aluminium Co. for aircraft parts for a number of years and early in the development stages it was discovered that the DTD type test piece was an unsatisfactory medium for the control of tensile properties. It was found, for instance, that the operator technique was a dominant factor in deciding whether any given bar would meet the specification and it was quite possible for any one operator to produce bars which gave widely different results. To a small extent the same effect is found with other materials when using this type of test piece, but with NA 350 it is accentuated.

Early Investigations

The scatter was minimised by training of the operators and constant supervision and the production of the alloy has been carried on for a number of years, quite successfully, on this basis. Nevertheless, it was felt that a test which depends to so large an extent upon the skill of the operator, could not be regarded as satisfactory. Such results are shown in Table I, from which it will be noted that the differences between bars from the same melt is so great as largely to mask any difference between the melts.

Very exhaustive tests of such factors as casting temperature, casting speed and angle of mould during casting, failed to reveal any certain method of producing reasonably consistent test bars. Examination of fractured bars, by means of sub-standard test specimens machined from the shoulders, revealed severe gradation of tensile properties in the bars. Some typical results of this investigation are given in Table IIA. The local

TABLE I.—TYPICAL RESULTS FROM SETS OF FOUR D.T.D. BARS
STANDARD DEVIATION OF TEST BAR 1·72 TONS/SQ. IN.

Melt.	1.	2.	3.	4.
U.T.S. Tons/sq. in.	15·7 17·6 19·2 16·5	14·0 17·0 16·7 18·0	22·1 20·7 17·7 21·8	17·8 18·3 20·2 16·3
Elongation %	6 7 10 7	6 8 8 10	19 16 11 16	7 6 10 7

TABLE IIA.—SURVEY OF TENSILE PROPERTIES IN D.T.D. TYPE TEST PIECES.

	Bar 1.		Bar 2.	
	U.T.S. Tons/sq. in.	% Elong.	U.T.S. Tons/sq. in.	% Elong.
Sub-standard result from top grip of bar as cast	14·2 14·7	9 7	14·0 14·1	7 8½
Initial result on 0·564 in. dia. D.T.D. bar	19·0	11	17·5	11
Sub-standard result from lower grip of test bar as cast	21·2 18·1	17 14	21·6 17·6	17½ 14

weakness at the top of the bar is due to shrinkage and it is caused by segregation of magnesium-rich liquid in the later stages of freezing, which is not replaced from the feeder head.

After the cause of the low properties in the portion of the bar adjacent to the feeder head had been established, a casting technique was evolved slowly, as a result of laboratory experiments and foundry tests. Advantage was taken of the alternative form of test piece commonly used for magnesium base alloys, which embodies a runner between the head of the bar and the parallel portion. This is intended to facilitate slow pouring and increase the feed. The bar was cast as slowly as possible without causing a cold shut and the time required to fill the 7 in. parallel portion was established at 15–20 seconds, a rather difficult feat requiring a high degree of manual dexterity.

In experienced hands this method was found to produce reasonable results, but required considerable labour and very close supervision. It could not be regarded as a satisfactory working basis and as a means of scientific control it left much to be desired. In Table IIB are shown results of substandard tensile tests taken from a DTD bar made late in this period, together with

TABLE III.—SURVEY OF TENSILE PROPERTIES IN D.T.D. TYPE TEST PIECE, CAST UNDER CONDITIONS OF INCREASED FEED.

	U.T.S. Tons/sq. in.	% Elong.	% Magnesium.
Top of bar..	17·5	10·5	—
	17·9	14·5	9·76
	16·4	7·0	—
Gauge Length	17·7	7·0	—
	17·3	10·5	10·13
	18·6	10·5	—
Bottom of bar	21·3	19·5	—
	20·8	14·5	10·41
	22·0	18·0	—

SURVEY OF TENSILE PROPERTIES OF "B" TYPE TEST PIECE CAST FROM THE SAME MELT.

	U.T.S. Tons/sq. in.	% Elong.	% Magnesium.
Grip	19·2	10·5	—
	16·3	9·0	9·84
	19·3	10·5	—
Gauge Length	21·8	12·5	10·19
	21·3	14·5	—
Grip	19·8	12·5	—
	16·3	9·0	9·94
	19·2	10·5	—

analyses for magnesium of the broken test specimens. It will be noted that some improvement had been effected, but that the bar was still not homogeneous. The difference in the magnesium content may be taken as evidence of segregation.

Undercarriage Support Beam

The difficulty was emphasised by the continually expanding production of castings in NA 350 and with the advent of the Lancaster Undercarriage Support Beam it became vitally important. In many respects the Beam is an unusual casting and its history is, to some extent, inseparable from the work it is proposed to recount here.

Originally it was designed to be made as a built-up box girder structure but production difficulties were so great, in view of the huge quantity projected, it was decided that the Beam should be made as a casting and DTD 300 was chosen for the purpose. It was the first aircraft casting to be produced with a reserve factor of 1½. The usual reserve factor is 2 and most aircraft castings are designed on this basis. In view of the reduction in reserve, it was required that a number should be tested to destruction and that these tests should be carried out at intervals and so cover the whole of the production. The weight of the casting is 126 lbs. Together with runner and risers it is about 260 lbs. and the casting of two beams requires almost 600 lbs. of liquid metal. It was first made as a sand casting, but a die-casting technique was soon evolved and the casting has been made by this method for some time past.

Use of Statistics

Throughout the investigation it is now proposed to describe, statistical methods have been used and all conclusions are based upon statistical inferences. It will be realised that the analysis of so large a body of data, as that represented here, could not otherwise be accomplished satisfactorily. The methods used for the calculations are the usual processes for the analysis of variance, the comparison of means and the calculation of correlation and regression coefficients.

Also, most of the investigation was carried through with the active collaboration of A.I.D. A proportion of the tests were carried out in their laboratories, and in the final stages, the results were analysed independently. Similar conclusions were reached by both parties.

Throughout the work it was possible to maintain the composition and heat-treatment within comparatively narrow limits and so prevent undue interference from these variables.

Properties of Sand Castings

In the first place then, and at the request of the inspection authorities, an investigation was made into the distribution of mechanical properties in sand cast beams.

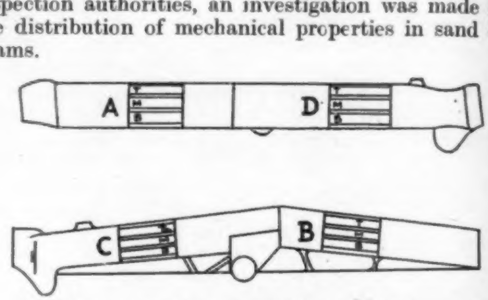


Fig. 1.—View of stations at which sections were taken from undercarriage support beams.

Over a period of two months, thirty castings were selected and test pieces taken from the twelve stations illustrated in Fig. 1. These stations were selected with reference to the stresses imposed upon the casting in service and the averages of the test results have been taken as an index of the strength of the casting for the purpose of this investigation.

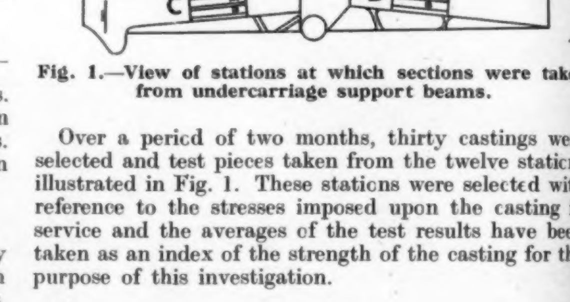


Fig. 2.—Relationship between DTD type test pieces and sectioned sand cast beams

In Fig. 2, the means of the beam results are plotted against the mean values obtained from the relevant sets of four test bars.* It will be noted that although the quality of the metal, as measured by the DTD test

* In a few cases four bars were not available.

pieces, shows considerable variation, yet the casting is comparatively inert.

The correlation coefficient for these results is $+0{\cdot}38$. Correlation of means of sets of test pieces with the means of the castings gives the maximum value possible under the circumstances, since the standard error of the bars is progressively reduced as the number is increased. The correlation coefficient then tends to some limiting value determined by the characteristics of the casting and the distribution of the sample, and for practical purposes the value of $+0{\cdot}38$ may be taken as near to this limit. Similarly, as the number of bars per set is reduced the correlation coefficient is diminished. Therefore, if it is assumed that only one bar is tested, as is the usual practice, the coefficient for this sample is $+0{\cdot}14$ (Table III). This reduction is caused entirely by the large standard deviation of the DTD test piece.

TABLE III.—CORRELATION COEFFICIENT BETWEEN D.T.D. BARS AND MEAN OF 12 BARS FROM SAND CAST BEAMS. U.T.S. VALUES.

One Bar.	Mean of Two Bars.	Mean of Four Bars.
+0·14	+0·32	+0·38

CORRELATION COEFFICIENT BETWEEN "E" BARS AND MEAN OF 12 BARS FROM DIE CAST BEAMS. U.T.S. VALUES.

One Bar.	Mean of Two Bars.	Mean of Four Bars.
+0·34	+0·42	+0·45

Investigation of Test Pieces

Discussion of these results, and all the other evidence available, led to the obvious conclusion that from the view points of both metallurgical control and correlation with castings, a test piece with a lower deviation was very desirable and an experimental programme was undertaken to determine how this could be effected.

It was decided that the main defects inherent in the DTD bar were insufficient feed and lack of control on the rate of pouring by the mould.

Four designs of test bar, each of which was intended to be an improvement upon the DTD bar, in one or both respects, were selected for initial tests. These bars, as cast, are illustrated in Figs. 3 to 6.

Keel bar 1 (Fig. 3) was cast in a sand mould with a vertical joint. The bar was intended to give increased feed with close control over the rate of pouring.

Keel bar 2 (Fig. 4) was made in a one piece sand mould. It was designed to give increased feed and, also, some control over the rate of pouring.

Fig. 5 illustrates a horizontal chill bar, referred to in this report as "Bar C." This bar was expected to have very much increased feed over the DTD bar.

The fourth type of bar examined is illustrated in Fig. 6. It is the sand, cast to shape bar which is of common use in the U.S.A. and is referred to hereafter as the "A" type.

The preliminary trials of these bars consisted of several casts of 2 to 6 each, together with the DTD bars for comparison. During these tests, variation of the dimensions of the ingates of the keel bars and the gates and type of mould (skin dried, etc.) of the "A" type bar were examined.

The sand cast keel bars were found to give scattered results and, as surveys carried out by sub-standard tests showed the properties to be severely graded throughout the bar, these types were discarded.

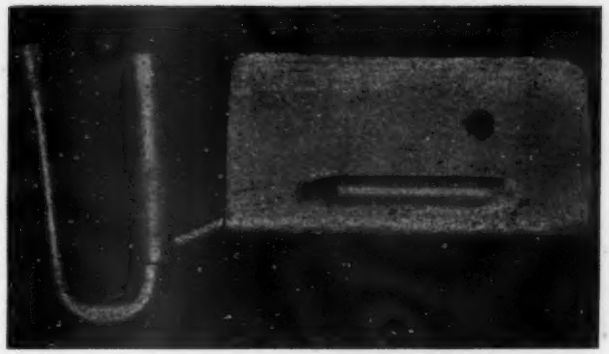


Fig. 3.—Sand cast keel bar 1.

Some results of early tests on the "C" type bar are given in Table IV, together with the DTD results for comparison from which it will be seen that the "C" bar gave a lower standard deviation than the value expected of DTD bars. The results were considered sufficiently encouraging to give this bar a trial under production conditions. Sets of three "C" bars were cast with three DTD bars for approximately 300 melts.

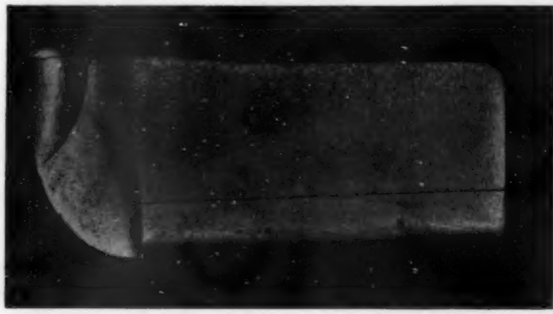
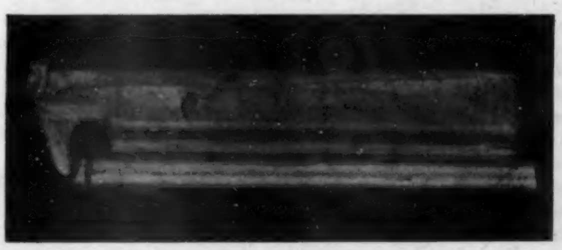


Fig. 4.—Sand cast keel bar 2.

The whole of these results are not reproduced, but the properties from the last 20 heats are summarised, also in Table IV. They show that the Standard Deviation obtained in the initial experiments was not realised under production conditions and it was considered that this was probably due to the original bars having been cast by one operator, so reducing the personal error. Work on this type of bar has been suspended, although it is thought a satisfactory bar could be developed, particula ly if due attention was given to the gating system.

Early tests of the "A" type bar also gave encouraging results (Table V). The standard deviation

Fig. 5.—Horizontal chill bar, type C.



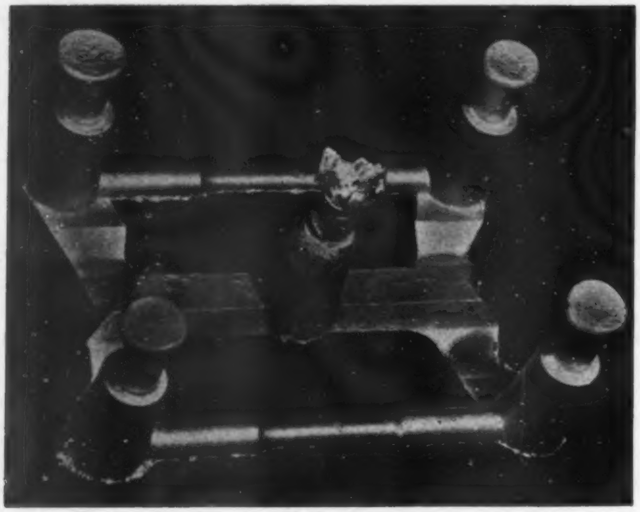


Fig. 6.—Sand cast test piece, type A.

TABLE IV.—TENSILE RESULTS FROM EARLY CASTS OF "C" TYPE BARS IN COMPARISON WITH D.T.D. TYPE, UNDER EXPERIMENTAL CONDITIONS.
STANDARD DEVIATION OF "C" TYPE BAR 1·10 TONS/SQ. IN.

	U.T.S. Tons/sq. in.	% Elong.
D.T.D. Type	19·1 18·1 20·7	13 9 13
"C" Type..	22·9 21·3 21·5 19·9 22·5 20·8	23 20 16 10 21 19

SUMMARY OF TENSILE PROPERTIES FROM A SAMPLE OF 20 SETS EACH OF 3 "C" TYPE BARS AND 3 D.T.D. TYPE FROM THE SAME MELTS. BARS CAST UNDER PRODUCTION CONDITIONS.

	Type of Bar.	
	D.T.D.	"C"
Mean U.T.S. Tons/sq. in.	18·24	18·08
Standard Deviation of U.T.S. due to Test Bar Tons/sq. in.	1·32	1·24
Mean Elongation % on $4\sqrt{\text{area}}$	11·4	10·1

obtained was 0·88 tons/sq. in., a very considerable improvement upcn the DTD bar, but the results of a further trial summarised in the same Table, were not so satisfactory. In this second experiment, the low standard deviation of the "A" bar found in the initial test was not obtained and it was thought that in this case the increase may have been due to the sensitivity of the bar to notch effects associated with the cast surface and that greater variations had arisen during the production run than in the initial experiments, which were carried out under clcser supervision.

Criticism of "A" Bar

But in view of the many practical advantages of this type of bar it was decided to continue the investigation further. This design may be represented essentially as an ideal casting, in which the first liquid metal to enter the mould flows to the furthest point. A well defined temperature gradient is established during freezing, hence promoting progressive solidification. It also embodies an accurately controlled gating system, with large reservoirs, so that control of the pouring speed by the operator is relatively unimportant. But, also, it is intended to be cast to size and is, therefore, subject to a certain amount of inaccuracy in this respect. Further, its cross sectional area is 0·2 sq. in., whereas the British standard bar is 0·25 sq. in.

Therefore, in order to explore the effect of increasing the mass of the casting, a further pattern was made to give bars 0·564 in. dia., cast to size (B type) and a third one to give 0·564 in. dia. plus machining allowance (D type). The diameter of this bar was 0·6 in. and it was intended to show the effect of machining. These larger patterns were scaled up so that the ratio of volume of test bar to volume of riser is approximately the same.

The tests of these types are given in Table VI. It will be noted that experimentally the machined "D" type bar gave higher and slightly more regular results and, in addition, it was more satisfactory, from the testing point of view, because of its precise diameter. The "B"

TABLE V.—TENSILE RESULTS FROM EARLY CASTS OF "A" TYPE BARS IN COMPARISON WITH D.T.D. TYPE BARS CAST UNDER EXPERIMENTAL CONDITIONS.
STANDARD DEVIATION OF "A" TYPE BAR 0·88 TONS/SQ. IN.

	U.T.S. Tons/sq. in.	% Elong.
D.T.D. Type	19·8 16·7	13½ 8½
"A" Type	21·0 21·4 20·0 21·2 20·4 18·4 19·5 20·1 20·1 19·9	14 15 12 15½ 13½ 9 12 13 11 11

SUMMARY OF TENSILE PROPERTIES FROM 15 CASTS OF TWO D.T.D. AND TWO "A" TYPE BARS, CAST UNDER PRODUCTION CONDITIONS.

	Type of Bars	
	D.T.D.	"A"
Mean U.T.S. Tons/sq. in.	19·0	18·8
Standard Deviatoon of U.T.S. due to test bar. Tons/sq. in.	1·28	1·39
Mean Elongation % on $4\sqrt{\text{area}}$	12·5	11·7

and "D" bars were given a trial under prcduction conditions and the results, also in Table VI confirm thcse of the initial experiment.

Types "E" and "F"

The next development was the modification of the "D" pattern to produce four bars on the cne spray. Also the "as cast" diameter of the gauge length was increased to ⅝ in. Two types, referred to as "E" and "F," were tried and are illustrated in Figs. 7 and 8. The "F" or diamond pattern was devised with the object of displacing the metal junction from the gauge length, thereby reducing the tendency for defects to occur in this region, and at the same time retaining to some extent, the advantages of double gating.

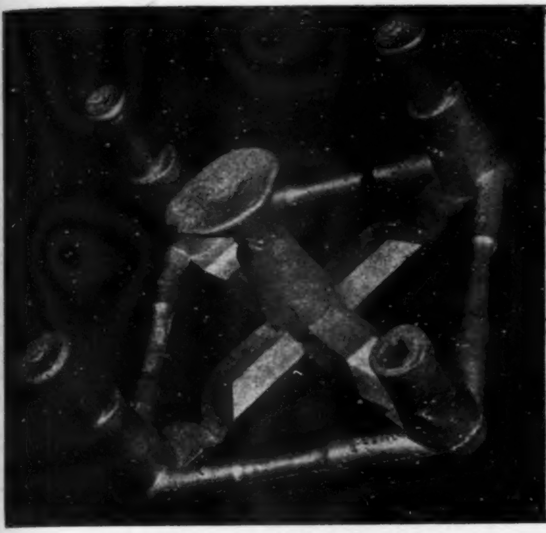


Fig. 7.—Sand cast test piece, type E.

Fig. 8.—Sand cast test piece, type F.

TABLE VI.—TENSILE RESULTS FROM INITIAL CAST OF "A," "B," AND "D," IN COMPARISON WITH D.T.D. BARS. BARS CAST UNDER "EXPERIMENTAL CONDITIONS.
STANDARD DEVIATION OF "B" TYPE 1·71 TONS/SQ. IN.
STANDARD DEVIATION OF "D" TYPE 0·354 TONS/SQ. IN.

	U.T.S. Tons/sq. in.	% Elong.
D.T.D.	21·5	18
	21·7	19
	21·1	16½
"A" Type	22·2	18
	19·5	15½
B Type	22·9	22½
	22·7	17
	22·2	19
	22·0	18½
	18·3	9 Blow hole
	22·3	19½
D Type	23·5	26½
	22·7	20
	22·6	20
	23·1	27½
	22·6	20
	22·8	22

SUMMARY OF TENSILE RESULTS OBTAINED FROM PRODUCTION RUN OF "B," AND "D" TYPE BARS. TWO BARS OF EACH TYPE CAST FROM 28 HEATS.

Type of Bar.	U.T.S. Tons/sq. in.		% Elong.
	Mean.	S.D. of Test Bar.	Mean.
"B"	18·10	0·914	9·77
"D"	18·50	0·811	10·35

As a further attempt to avoid defects in the bars, both these types were tried single gated by stopping one pair of gates ("ES" and "FS" bars). In the case of the "FS" bars, the shorter gates were stopped off.

The results of 23 sets of four bars from each of these four types are summarised in Table VII, together with the corresponding DTD bars. The results are also given as histograms in Figs. 9, 10 and 11. In considering these test bar types, the differences between the elongations are considered to be of secondary importance to the U.T.S. values and accordingly they are not discussed in detail. Similarly, the mean U.T.S. value is taken

TABLE VII.—SUMMARY OF TENSILE PROPERTIES FOR 23 SETS OF 4 BARS OF EACH TYPE.

	D.T.D. 300	"E"	"ES"	"F"	"FS"
Mean U.T.S. Tons/sq. in.	18·52	19·80	18·19	19·55	19·05
S.D. of Test Bar. Tons/sq. in.	1·36	1·01	1·19	1·32	0·872
S. D. of Melts. Tons/sq. in. (Includes S.D. of Metal)	0·995	0·709	0·723	0·835	0·549
Total S.D. Tons per sq. in.	1·68	1·23	1·40	1·57	1·03
Mean % Elongation	11·1	11·7	9·4	11·5	10·6

into account only after the scatter of results has been considered.

Analysis of Variance

In Table VII the variance of the U.T.S. values has been analysed into two parts. Firstly, a variance due to factors primarily associated with the test bar (test bar variance) and secondly, after allowing for the sampling variance, a variance of means of sets around the grand mean. This latter includes the variance due to changes in metal quality (metal variance), and is of importance in assessing the relative response of the test pieces to such changes.

The cast to shape bars all give lower standard deviations of U.T.S. values than the DTD type. This would indicate that any of these types would represent an improvement upon the DTD. bar. The single gated bars, from the point of view of feeding the gauge length, would be expected to have a less favourable temperature gradient than the corresponding double gated bar and would probably give a greater variation of properties with casting temperature. As they showed no advantage to compensate for this probable defect, they were discarded. Similarly, the "F" type showed no advantage over the "E" type which would justify the slightly more complex pattern and larger moulding box required.

It is somewhat difficult to assess the full significance of the "metal" variances as shown for instance, by comparison of that for the "FS" bar with that for the "E" bar. In an ideal experiment, differences in this

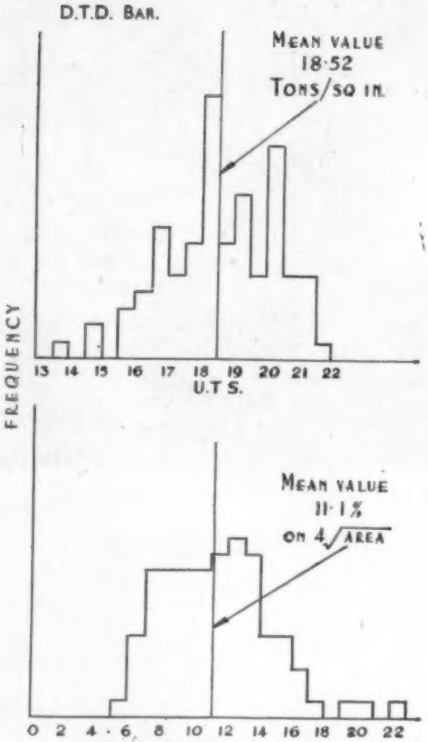


Fig. 9.—Histograms of tensile results from 23 sets of 4 D.T.D. test pieces.

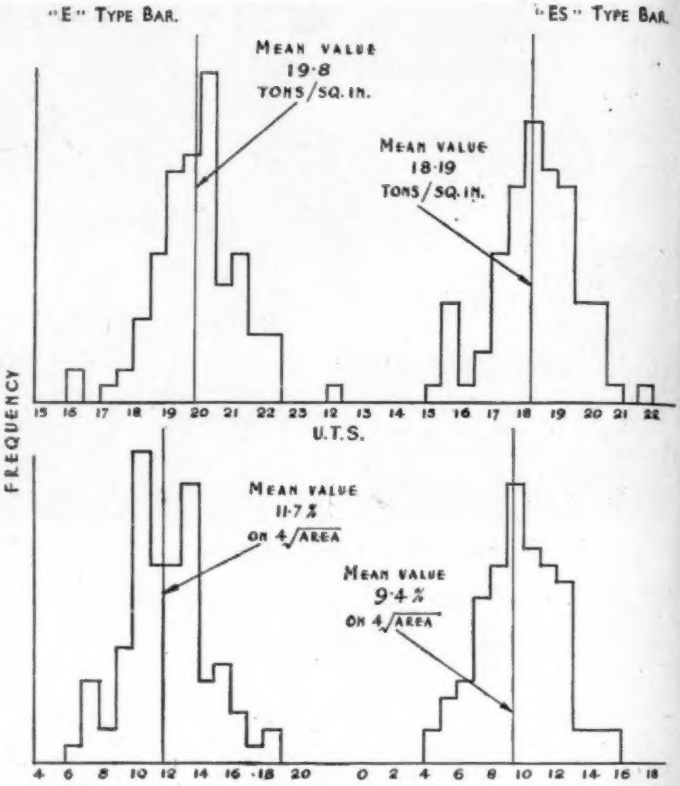


Fig. 10.—Histograms of tensile results from 23 sets of 4 E and ES test pieces.

variance would represent different sensitivities of the test pieces to changes in metal quality and other things being equal, the higher this variance, the more useful would the test bar be as a measure of metal quality. The usefulness of the experiment in evaluating this property has been largely vitiated by the failure to realise, at the outset, the importance of gauge diameter on the strength of the bars, which aspect is discussed at some length subsequently. In consequence it is not possible to say how far the low residual variance of the "FS" type is due to its being insensitive to metal changes and how far it is due to the experimental procedure. This is essentially a property of the test piece and could, under extreme conditions, vitiate its usefulness as an instrument of control. Attention is drawn to this point because of the author's present opinion that such superficial characteristics should not be allowed to superpose themselves upon the metal variance.

A repeat experiment was carried out on the DTD and "E" type bars. This comprises 28 sets of 4 bars of each type and the results are summarised in Table VIII, which confirm the findings of the earlier trial. The "E" bar gave a U.T.S. value 1 to 1¼ tons/sq. in. higher, with a standard deviation of approximately 1·0 ton/sq. in., as compared with 1·3 tons/sq.in. for the DTD bar. The elongation value was approximately ½% greater It is considered that when the nature of the experiment is taken into account, this is very close agreement and

TABLE VIII.—SUMMARY OF RESULTS OF SETS OF 4 D.T.D. AND 4 "E" BARS FROM 28 MELTS.

	D.T.D.	"E"
U.T.S. Mean. Tons/sq. in.	18·28	19·46
Standard Deviation of Test Bar. Tons/sq. in.	1·28	1·07
Standard Deviation of Melts. Tons/sq. in.	1·55	1·39
Total Standard Deviation. Tons/sq. in.	2·01	1·75
% Elongation. Mean. $4\sqrt{\text{area}}$	11·0	11·4

that if the experiment were repeated at a more remote time, greater differences might be recorded.

In Table IIB are given typical results from a detailed examination of the "E" bar. From these it will be seen that the distribution of properties is more symmetrical than in the corresponding DTD bar, and although the magnesium results still indicate segregation, this is smaller and does not occur at the expense of the gauge length.

Effect of Machining

It was essential for the purpose of statistical analysis to obtain an equal number of tensile results in each group of bars tested and, since a few bars were found to contain small defects in the gauge length, throughout the experimental period, it was the practice to machine the bars to 0·564 in., 0·505 in. or 0·437 in. diameter, using the greatest of these diameters which would give a bar free from obvious defect on its machined surface.

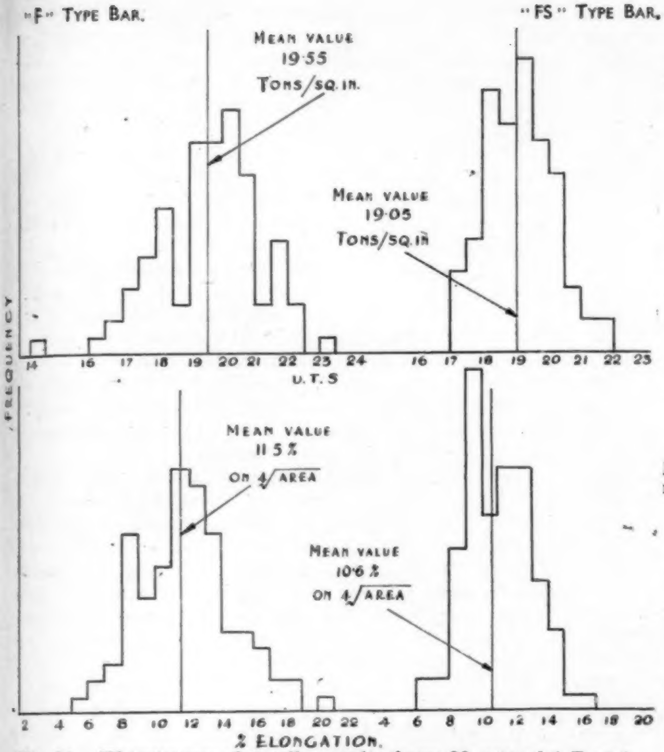


Fig. 11.—Histograms of tensile results from 23 sets of 4 F and FS test pieces.

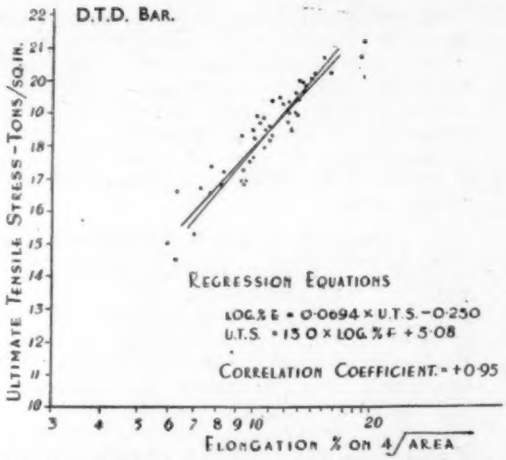


Fig. 12.—Regre sions between mean U.T.S. and mean log. % E of D.T.D. bars from the 23 and 28 sets summarised in Tables VII and VIII.

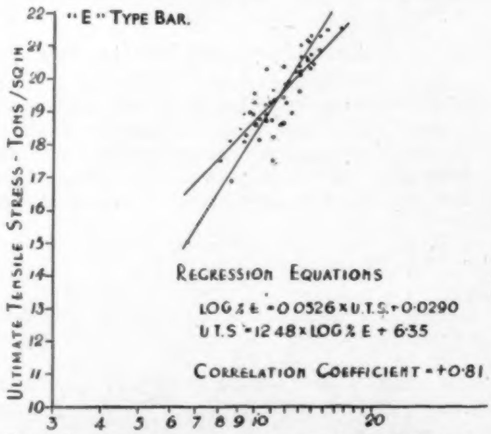


Fig. 13.—Regressions between mean U.T.S. and mean log. % E of E bars from the 23 and 28 sets summarised in Tables VII and VIII.

To investigate the effect of this machining, 38 sets of three bars were obtained in which each set came from one cast and one bar in each set was tested at each of the three nominal diameters. These results are analysed and are shown in Table IX. The U.T.S. and elongation values are very much reduced by the increased machining, but the scatter of results at any given diameter is not largely affected.

TABLE IX.—SURVEY OF TENSILE PROPERTIES FROM SETS OF THREE "E" TYPE TEST BARS FROM 38 CASTS. EACH SET CONTAINED ONE BAR TESTED AT EACH OF THE FOLLOWING NOMINAL DIAMETERS, 0·437 in., 0·505 in., and 0·564 in.

U.T.S. VALUES.

Nominal Diameter	0·437 in.	0·505 in.	0·564 in.
Mean value. Tons/sq. in.	17·88	18·32	19·11
Probability of chance occurrence	2–5%		<0·1%
Standard Deviation.. Tons/sq. in.	1·38	1·50	1·28
Probability of chance occurrence	60% approx.		35% approx.
Grand Mean	18·44 Tons/sq. in.		
Total Standard Deviation	1·47 " " "		

ELONGATION VALUES.

Nominal Diameter	0·437 in.	0·505 in.	0·564 in.
Mean % Elongation on $4\sqrt{\text{area}}$	8·6	9·1	10·4

The method used in assessing the differences is the statistical "t" test, which reveals the probability that these or greater differences could arise by chance variation. It is shown that the probability of this occurring for the first difference, 0·564 in. dia. to 0·505 in. dia., is less than 0·1%, and for the second difference, 0·505 in. dia. to 0·437 in. dia. is 2–5%. It must, therefore, be assumed that real differences exist.

Referring again to Table VI, which compares the "B" and "D" types of test piece, it is indicated here that the effect of the "as cast" skin is to reduce the tensile strength. This, too, is likely to be a real effect since the probability of chance occurrence is 5–10%. It would seem, therefore, that the effect of machining is first to improve the tensile properties, by diminishing the notch effect, and then to cause a reduction, as the outer layers of metal are removed. This supports the commonly held view that castings should be made as close to the final dimensions as possible and machining reduced to a minimum.

TABLE X.—STANDARD DEVIATION OF "E" TYPE BAR FROM PRODUCTION RUN AFTER STANDARDISING GAUGE DIAMETER AT 0·564 in. EACH SAMPLE REPRESENTS 54 SETS OF 4 BARS.

Sample.	Standard Deviation Tons/sq. in.	Mean U.T.S. Tons/sq. in.	Mean % Elong.
1	0·63	18·03	10·1
2	0·89	19·55	12·4

All subsequent work has been carried out on bars machined to 0·564 in. nominal diameter irrespective of whether or not a defect was visible. That this procedure results in a decrease in test bar standard deviation is confirmed by the results given in Table X, which gives values for two further samples taken at a later period. In other words, the effect of residual defects in the bar is less than the effect of the machining required to remove them.

Relation of U.T.S. and Elongation

The U.T.S./% Elongation relationships for the DTD and "E" type bars are compared in Figs. 12 and 13. Each point on these graphs represents the average of a group of four bars from the sets given in Tables VII and VIII. The elongation values have been plotted on a logarithmic scale, as this has been found to give an approximately straight line relationship with U.T.S. for this alloy. The appropriate regression equations are also given in Figs. 12 and 13 from which it will be seen that the "E" bar gives a slightly smaller elongation value for any given U.T.S. within the range tested, but the elongation varies with the U.T.S. value in a similar manner in each case.

Correlation with Die Castings

Having then tentatively established the superiority of the "E" type test piece in regard to scatter of results, it was decided that it should now be tested more extensively. Accordingly, arrangements were made for it to be used over a trial period of 12 weeks for the control tests on undercarriage beam castings and during this

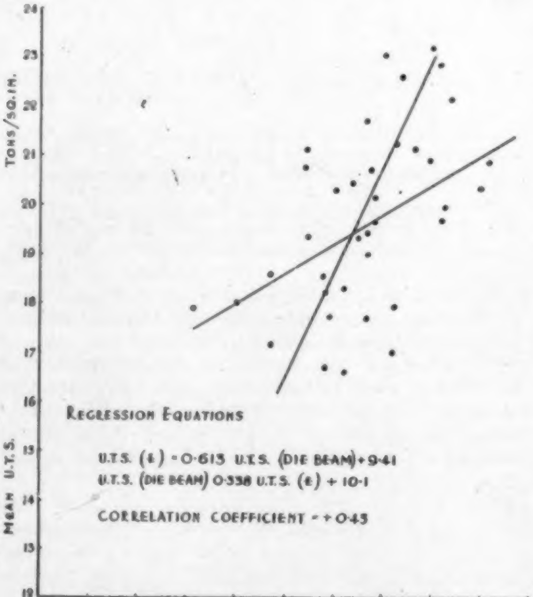


Fig. 14—Relationship between "E" type test piece and sectioned die cast beams.

time, to select a number of castings to be cut up and tested as had been done with the DTD bar. However, during the time taken to reach this stage, the change had been made from sand to die cast beams and necessarily the castings selected were die castings. They are not, therefore, strictly comparable with those examined earlier. A few comparison tests between DTD bars and die cast beams were made, but the number is considered to be insufficient to allow any useful conclusions to be drawn. These results are not included in this article.

The results for "E" type test pieces and die cast beams are given in Fig. 14, where the means of the twelve bars cut from the beam are compared with the means of the four relevant test bars. A correlation coefficient of $+0·45$ was obtained from these results, when the means of four test bars were used, which falls to $+0·34$ when only one test bar result is taken into account (Table III). The reduction is, therefore, much less than was found for the DTD bar, where the correlation coefficient was reduced from $+0·38$ to $+0·14$. This demonstrates the superiority of one "E" type bar over one DTD bar as a measure of metal quality, and indirectly, as a measure of comparative properties which may be expected from the castings.

On the broad question of how far test piece results may be taken as a measure of the strength of castings it should be noted that in the cases examined here, the maximum coefficient obtained was $+0·45$: This was obtained by using the means of the four test pieces, thereby reducing very considerably the standard error of this component. Even so, the interdependence is not of a very high order, and when only one test piece is used, the correlation falls to a still smaller value.

The extent to which correlation is possible is determined also by the variance of the tensile properties in the castings. These are affected by many factors peculiar to the casting processes; and invariably the tensile properties of castings will show unavoidable scatter. Again, as Figs. 2 and 14 indicate, different castings may show widely differing relationships. Both the castings examined here appear to be comparatively inert, in that they do not respond to the apparent changes as shown by the test pieces.

These three factors, the variance of the test piece, that of the casting, and the association which exists between them, determine the extent to which the properties of one may be taken as an index of the properties of the other. It follows, therefore, that only to a limited degree can the test piece results be used as a guide to the properties of the castings and, even so, only when the relationship between test piece and casting has been established, and the characteristics of the casting are known.

Results of Test Under Production Conditions

During the twelve week trial period nearly 5,000 "E" type bars and a similar number of DTD bars were tested. The former were used to cover the undercarriage support beams and the latter for all other castings. The metal used was drawn concurrently from a common melting unit, which supplied approximately equal quantities for both purposes.

From each cast, either four "E" or four DTD type bars were produced; three were submitted for normal A.I.D. examination, and the fourth was used for works control purposes. It is these control or check test bars that are dealt with here.

The distribution of the U.T.S. values from 923 DTD bars and 1,180 "E" bars are shown in Fig. 15. The mean U.T.S. of the DTD results is 17·97 tons per sq. in. and of the "E" bar results is 19·01 tons/sq. in. The standard deviations are 1·98 and 1·73 respectively.

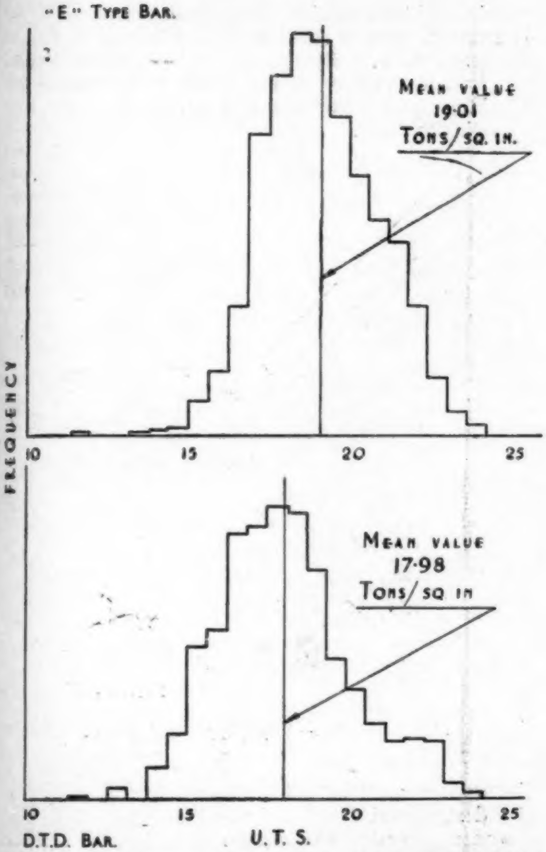


Fig. 15.—Histograms of ultimate tensile strength values from 1180 "E" type and 923 D.T.D. type test pieces cast during a production run of twelve weeks.

Histograms of the elongation values are shown in Fig. 16. These are constructed on a logarithmic elongation scale because the distribution then approaches closer to the normal.

The means and standard deviations of the logarithmic distributions are 0·982 and 0·167 for the DTD bar and 1·017 and 0·133 for the "E" bar. These mean values correspond to the geometric means of the arithmetic distributions and are 9·6% and 10·4% respectively, which may be compared with the arithmetic values of 10·5% and 11·1%. The probability of failure at the various levels given in Table XI have been estimated from the logarithmic distribution.

It should be noted that the standard deviations quoted above are large because of the time factor. They measure the effect of all causes of variation and these are likely to be more numerous with longer time. The standard deviation of the test piece is only one component of the larger quantity, and during this time it was calculated upon two samples of 54 melts from each of which four "E" bars were broken. The results are given in Table X, from which it will be noted that values of 0·66 and 0·89 tons per sq. in. were obtained.

From the results given in Table XI it is seen the "E" bar has been found to give mean values of very nearly 1 ton/sq. in. and 0·6% elongation higher than the DTD type. These figures in themselves would indicate

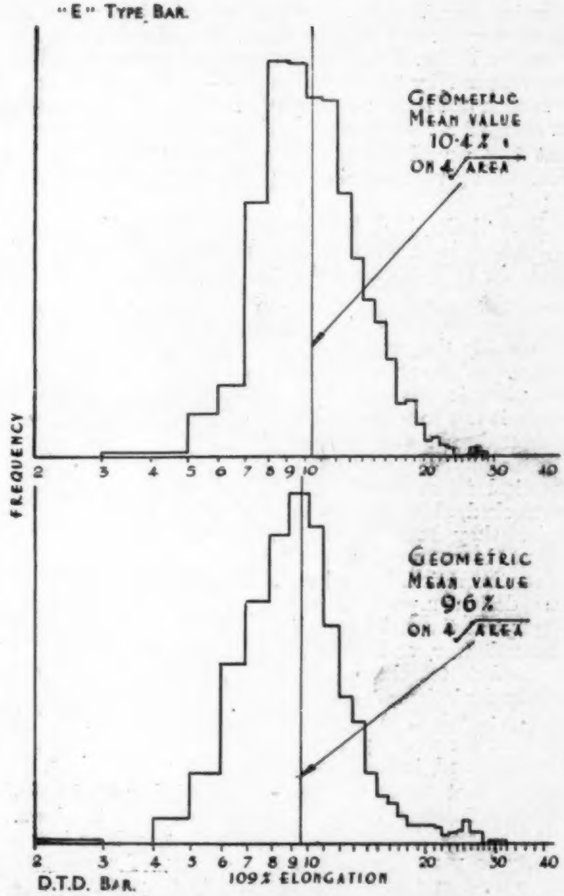


Fig. 16.—Histograms of elongation values from 1180 "E" type and 923 D.T.D. type test pieces cast during a production run of twelve weeks.

TABLE XI.—SUMMARY OF PRODUCTION RUN.

		Type of Test Piece.	
		D.T.D.	"E"
U.T.S. Tons/sq. in.	Mean	17·97	19·0
	Total S.D.	1·98	1·73
Elongation	Mean Log Geometric Mean % S.D. Log	0·982 9·6 0·167	1·017 10·4 0·133

PROBABILITY OF FAILURE AT VARIOUS LEVELS ASSUMING NORMAL DISTRIBUTION.

Minimum Limit for U.T.S. Tons/sq. in.		16	17	17½	18
Percentage of failures	D.T.D. "E"	16 5	31 12	41 19	51 28

Minimum Limit for % Elongation		7	7½	8
Percentage of failures	D.T.D. "E"	20 10	26 14	32 19

17 tons/sq. in. and 7½% for equivalent specification limits for the "E" type bar. This limit is satisfactory for the U.T.S., since the smaller deviation of the "E" type bars gives a smaller probability of failure, thus

reducing considerably the number of cases where a satisfactory melt would be failed by poor test bars.

As the U.T.S. is the more important property and is less affected by the personal element during testing, it is clear that the probability of failure should be less on elongation than it is on U.T.S. From this, it follows that $7\frac{1}{2}\%$ would be too high a value and 7% elongation gives a satisfactory probability in this respect.

These limits, 17·0 tons/sq. in. and 7% elongation have been sanctioned as new specification limits for DTD 300A for the "E" type bar.

Conclusion

Probably the greatest advantage of the "E" type test piece is the ease with which it can be made. The authors do not wish to convey the impression that the practical issues have been overlooked, although in this article they have to some extent been overshadowed by the theoretical discussion. The design represents an attempt at the reduction of personal error, and no skill is needed to obtain the smaller deviation. It should be emphasised that the whole of the work upon the "E" bar and, indeed, upon all the cast to shape bars was carried out with no technical intervention in the manufacture of the bars.

All that is necessary to cast satisfactory bars is the ability to pour approximately 9–10 lbs. of metal into the central runner sufficiently fast to keep the ingates choked, which is a simple matter as the chokes are situated low in the mould. The sprues prior to them have a considerable volume and this acts as a reservoir, so that inadvertent change in pouring rate does not affect the rate at which the bar is filled. The time required to fill the mould is 5–6 seconds, compared with 3–4 minutes to cast an equal number of DTD test pieces.

The cost may be a little greater in both material and labour, but the authors consider this to be trifling in view of the technical advantages gained, at least with this particular alloy.

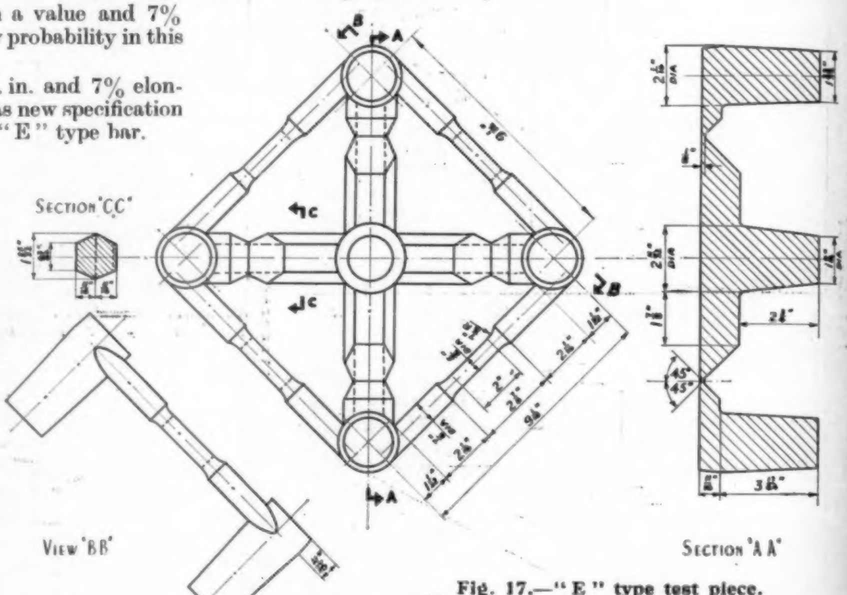


Fig. 17.—"E" type test piece.

The smaller scatter, which results directly from the better design, and the practical advantages, make the bar a more effective medium for metallurgical control and also considerably improve the somewhat uncertain relationship between bars and castings. A line drawing of the "E" type test piece is given in Fig. 17.

Finally, the authors wish to express their thanks to Mr. R. A. Nowlan, A.I.D. Headquarters, and Mr. F. H. Jones, Inspector in Charge, A.I.D., for their interest and assistance in carrying out this work.

Industrial Spectroscopic Group

At a meeting held in London on January 23 last, an Industrial Spectroscopic Group was formed under the auspices of the Institute of Physics. Mr. F. Twyman, F.Inst.P., F.R.S., of Adam Hilger, Ltd., was elected Chairman of the Group, and Mr. E. H. S. Van Someren, of Murex Welding Processes, Ltd., Honorary Secretary. The following were elected to serve as the first Committee: Lt.-Comdr. J. Convey (Admiralty Laboratory, Sheffield), Mr. B. S. Cooper (Research Laboratory, General Electric Co., Ltd.), Prof. H. Dingle (Imperial College, London), Dr. A. G. Quarrell (British Non-Ferrous Metals Research Association), Mr. E. W. H. Selwyn (Research Department, Messrs. Kodak, Ltd.), Mr. D. M. Smith (Messrs. Johnson Matthey and Co., Ltd.), Dr. S. D. Steele (Messrs. Babcock and Wilcox, Ltd., Glasgow), Mr. A. Walsh (British Non-Ferrous Metals Research Association).

This is the fourth subject group to be formed by the Institute in response to requests received from industrial and Government scientists. Their object is to provide regular opportunities for the interchange of knowledge and experience between specialists. Membership of this and other subject groups of the Institute is open to all interested, non-members of the Institute of Physics paying a nominal fee. Further particulars may be obtained from The Secretary, Institute of Physics, 19, Albemarle Street, W. 1.

Geological Investigation and Mineral Developments in the Colonies

The third lecture of the above series will be given on Thursday, February 28, at 3 p.m., by E. S. Willbourn, Esq., M.A., F.G.S. (Director of the Geological Survey of the F.M.S.), on "The Relationship of the Geological Survey Department to the Mining Industry of Malaya." The chair will be taken by A. Creech Jones, Esq., M.P. (Parliamentary Under-Secretary of State for the Colonies). The lecture, which will be illustrated, will be given in the Cinema Hall of the Imperial Institute, South Kensington, S.W. 7 (East Entrance), and will be followed by a discussion.

SECONDARY ALUMINIUM

By F. H. SMITH

Development Officer of ALAR

Just as the conservation of metals is essential in war-time, it has become very real in times of peace. Commonsense, as well as economic necessity, has for many years indicated the more prudent use of the ores available. The recovery of scrap and wastes, and their use with, or instead of, metals produced from their ores, is sound economics and entirely in accordance with the general principle of conserving natural resources. This principle is recognised in all metal-producing industries, although it was only applied on a general scale in the aluminium industry in this country during recent years. To-day, however, the conversion of aluminium scrap into suitable forms for re-use, is carried out under controlled conditions to meet specified standards, reference to which is made in this article.

THE principle of reclaiming previously used material is in no sense confined to the aluminium industry, neither has it evolved from difficulties of supply under wartime conditions, although the increased publicity given it during the past six years might have created these impressions. Since that day in early history when man first melted and recast his worn and battered bronze axe head, products manufactured from reclaimed material have constituted an ever-increasing proportion of the output of the metal-producing industries.

The use of the words, " secondary metal " is confined almost entirely to the aluminium industry; with other metals and alloys, for example, brass, cast iron and steel, no distinction is made between products manufactured from reclaimed material and those produced wholly or partly from virgin metal. In these latter industries scrap is, of course, a raw material of major importance, and it is the exception rather than the rule for the alloys to be produced from virgin sources only.

The composition of many alloys, such as those of copper and of iron, can be modified considerably by the removal or reduction of some of the alloying elements as a result of suitable furnace (or other) treatment. Similar practice is far more difficult with the alloys of aluminium, and although methods are known by which relatively pure aluminium can be obtained from aluminium alloys, these are not in general commercially operated, since they do not permit the economic production of the metal. The further use of the many forms of secondary raw material—*i.e.*, redundant or obsolete parts, sheet cuttings, machinings, etc., is largely governed by composition, and changes in alloy contents are made principally by dilution with pure or lower alloyed aluminium, by addition of hardener alloys, or by the mixing of batches of different compositions. Some of the material is, of course, returned to the fabricator, for example to the rolling mills to be used for the production of further rolling billets of similar composition, but a very large proportion is employed in the manufacture of casting alloys.

Early Efforts in the Use of Scrap

As would be expected, the relatively low melting temperature of aluminium, and the possibility of using very simple equipment led to early attempts to make use of the various scrap arising from the manufacture of aluminium components, by conversion into the form of remelted ingots for casting purposes. It soon became apparent that the type of raw material available was not suitable for treatment in simple furnaces, or by normal foundry technique. Sheet cuttings, turnings and similar forms of material have a large surface area-to-volume ratio, and in the case of aluminium, this surface carries a natural thin film of aluminium oxide. Since the density of alumina does not differ greatly from that of liquid aluminium, unless a treatment involving a specialised technique and equipment is employed, this aluminium oxide remains suspended throughout the liquid melt, and the product is an alloy which is useless for most practical purposes. There are, of course, many other considerations. Moisture, oil, other metals and non-metallic foreign matter must be removed from the raw materials, and the ingots produced must be free of non-metallic inclusions and of dissolved and entrapped gases, and they must be of a composition suitable for foundry use.

Despite these most obvious requirements, the opportunity of producing and selling very cheap aluminium alloys attracted the attention of a considerable number of people with little or no technical knowledge, who remelted and ingotted all kinds of miscellaneous scrap with little attempt at segregation, and with no proper melting control. It was inevitable that the sale of this metal containing gas, oxide, inclusions, etc., should produce false and unfortunate impressions among the users of aluminium of the very limited application of aluminium produced from secondary material. The few producers of scientifically controlled and manufactured secondary aluminium, who were in existence in the early 1930's, were faced with the very difficult task of overcoming the damaging reputation which had become established by the smaller producers of inferior alloys.

One of the results of the reluctance of industry to use large quantities of secondary aluminium was the export of thousands of tons of valuable aluminium scrap to the Continent and elsewhere, where its real value was appreciated, and where industry was able to use this cheap source of raw material to very good advantage.

Reclamation an Economic Neccessity

In the years that followed, the application of high-quality secondary aluminium increased slowly, but it was not until 1939 that the national consciousness was awakened to the economic necessity of utilising scrap aluminium. Faced with the prospect of war in which aluminium aircraft would undoubtedly play a major part, realisation of the limited capacity for the production of aluminium of these islands, occasioned great concern. It was not safe to assume that the production of immense quantities of this metal in the U.S.A. and in Canada provided the solution to the supply problem. Whether or not it would be possible to transport across the Atlantic the vast amounts of aluminium that would be required, could not at that hour be foreseen.

The alternative was to make use of every available source of aluminium within this country, and the vital importance of this policy was symbolised to every citizen in Lord Beaverbrook's call to housewives for aluminium. In order that all types of available aluminium should be used to the maximum advantage, the scrap-segregation scheme, for which the Light Metals Control was so largely reponsible, was introduced into all aircraft factories, machine shops, engineering works, etc., throughout the country. This segregation scheme and the control of the disposal of aluminium obtained, marked a milestone of the utmost significance in the progress of secondary aluminium. In the past, much of the material upon which the industry relied had been mixed with little regard to composition, and where efficient sorting was uneconomical or impracticable, was used for a debased or lower grade alloy. Now, it became possible to produce much larger quantities of higher-grade alloys, and with the experience gained in the previous years, and an improved knowledge of the effect of so-called impurity elements, new specifications were drawn up to ensure that the material available was converted into those compositions which could most usefully be employed. The need in the production of secondary aluminium for a high order of technical skill and for the most modern equipment was appreciated by the Ministry of Aircraft Production. This Ministry was responsible for the erection of a number of new factories which were operated by those manufacturers whose products in past years had demonstrated their knowledge of the problems of secondary aluminium production, and of the necessity for maintaining the highest standards of quality.

Improved Methods to Establish Standards of Quality

Improvements in methods of wet-chemical analysis, and the development of new physico-chemical methods such as those involving the use of the absorbtiometer, the spectrograph, and the polarograph, have contributed to a large extent to the high standards shown by secondary aluminium by making practicable the routine estimation and control of small amounts of impurity elements. Modern analysis methods have made possible the inclusion in specifications of the impurity limits which practice has shown to be permissible.

Most specifications for aluminium alloys were drawn up long before the beginning of the 1939-45 war, when only limited evidence was available of the effect upon physical and chemical properties of elements other than those which were the main alloying constituents, and at a time when the unsatisfactory conditions of manufacture described earlier still obtained in certain instances. It is understandable therefore that for the

TABLE I.

Designation	Chemical Composition (a)											Mechanical Properties (b)			Casting Characteristics			Uses and General Notes
	Cu %	Mg %	Si %	Fe %	Mn %	Ni %	Zn %	Pb %	Sn %	Ti %	Other Elements %	Minimum Ultimate Tensile Stress Tons/sq.in	Minimum Elongation % on 2 in.	0·1% Proof Stress Tons/sq.in (c)	Sand Casting	Gravity Die-casting	Pressure Die-casting	
L.A.C. 113B	2·5 4·5	0·1	1·2	1·0	0·5	0·5	9·0 13·0				Pb+Ni+Sn+Mn <1·0	9·0		2·5	G	U	U	General purpose sand-casting alloy.
ALAR 502·Z6	4·0 6·0	0·15	2·5	1·0			5·0 7·0				Pb+Ni+Sn+Mn < 1·0 Pb+Sn <0·5 Al > 84	8·0			G	F	U	Sand-casting alloy for low stressed parts.
L33	0·1		10·0 13·0	0·6	0·5	0·1	0·1	0·1	0·04	0·2	Modifying Agents <0·3	10·5	5	3·5	E	E	G	Alloy suitable for large or intricate castings and thin sections where ductility, pressure tightness, and corrosion resistance are required. Similar to BSS 702.
ALAR 00·12	0·4	0·15	10·0 13·0	0·7	0·5	0·1	0·2	0·1	0·05	0·2	Modifying Agents <0·3 Cu+Zn <0·5 Pb+Sn <0·1	10·5	3·5	3·5	E	E	G	ALAR 00·12 is similar to L.33, but has lower corrosion resistance and better machinability.
ALAR 00·5	0·1	0·1	4·5 6·0	0·8	0·3	0·1	0·1	0·1	0·05	0·2	Pb+Sn <0·1	7·5	3	-	G	G	G	Goodcasting alloy with high corrosion resistance.
L.A.C. 112A	0·75 2·5	0·2	9·0 11·5	1·0	0·5	1·5	1·2				Cu+Ni <2·0 Others <0·5	8·0			F	G	G	General purpose alloy especially suitable for pressure diecasting.
D.T.D. 428	6·0 8·0	0·1	2·0 4·0	1·0			2·0 4·0				Pb+Ni+Sn+Mn <1·0	8·0		5·5	F	G	F	General purpose gravity diecasting alloy.
D.T.D. 424	2·0 4·0	0·15	3·0 6·0	0·8	0·3 0·7	0·35	0·2	0·05		0·2	Fe+Mn <1·2	9·0	2	5·0	G	G	G	General purpose alloy having good combination of foundry and mechanical properties.
L.A.C. 10	9·0 10·5	0·15 0·35	0·6	0·2 1·0	0·6	0·5	0·1	0·1	0·1		Fe+Mn <1·4 Pb+Sn+Zn <0·2				F	G	U	Hard wear resistant alloy, suitable for service at elevated temperatures—e.g., for medium duty pistons. Good machining and polishing qualities.
L34 "Y" Alloy	3·5 4·5	1·2 1·7	0·6	0·6		1·8 2·3	0·1	0·05	0·04	0·2	Si+Fe <1·0 Sn+Zn <0·1	10·0		8·5	F	G	U	"Y" alloy is used where high temperature strength is required—e.g. for high duty pistons and cylinder heads.

(a) Single figures denote maximum contents.
(b) D.T.D. Sand Cast Test Bar.
(c) Typical Figures.

E = Excellent.
G = Good.
F = Fair.
P = Poor.
U = Unsuitable.

high service requirements of aircraft components (there were few specifications for aluminium other than for aircraft) where unnecessary risk was intolerable, the use of aluminium alloys involving unknown factors of behaviour, could not be justified. With the increased knowledge of composition effects, with improved technique in the manufacture of secondary aluminium, and, in 1939, with the necessity of utilising all available sources of aluminium, it became possible, and indeed, nationally essential, that the clause permitting only the use of primarily-produced aluminium in the manufacture of alloys to aircraft specifications should be relaxed to include the use of secondary aluminium. There remained exceptions in the case of certain alloys which, because of their composition, could only be made from special high-purity aluminium. The performance of all these alloys under exacting flying and service conditions has fully justified the policy of incorporating secondary aluminium, and it is now accepted that the quality of an alloy depends only upon its composition and the standard of workmanship employed on its manufacture.

In addition to those which existed before 1939, a number of new specifications for casting alloys were introduced during the war years. With the exception of one alloy, these or similar compositions were already widely used under various names. This provides an excellent opportunity of illustrating the general policy of secondary aluminium producers. Where so-called commercial alloys with vaguely-defined composition have been found to meet a real demand from industry, they are used as the bases for specifications in which their composition and mechanical properties are clearly defined. The user is thus protected from any variation in the properties and behaviour of the alloy since the composition is no longer left to the arbitrary interpretation of the producer, and the quality of the material is ensured by compliance with mechanical requirements. Two other points may conveniently be stressed at this juncture. Firstly, that it is in the interest of both founders and producer that the number of specifications should be limited to a miniumm, and that the user as far as is practicable should refrain from using " special " compositions, and certainly should do nothing to encourage the use of alloys which are not completely defined by specifications. Secondly, it is essential that in the development of new alloys, particular emphasis should be laid upon the desirability of good casting characteristics, and not upon superlative mechanical properties obtainable only in test specimens cast under ideal conditions. A short range of alloys covering most casting requirements is given in Table I.

Scrap as a Raw Material

The need for a very considerable expansion in export trade, if a high standard of living at home is to be maintained, has been well emphasised to the public in the daily press. The maximum utilisation of available resources within the country, and the avoidance of unnecessary importation is an equally important principle of national economy. One of these resources of no little importance is the raw material used for the production of secondary aluminium. It is essential in the national interest, that all useable aluminium scrap should be returned to circulation, and that for the employment of such material to the maximum advantage the careful segregation of scrap should continue. The export of large tonnages of this valuable raw material cannot again be permitted ; manufacturers have demonstrated during the war that plants within this country are quite capable of handling all the aluminium scrap. It is very desirable that aluminium should be exported, but only in the form of alloy ingots or finished articles—*i.e.*, as a product involving the employment of British labour.

Importance of Secondary Aluminium

The magnitude of the production of secondary aluminium is demonstrated by the statistics released recently by the Light Metals Control. In the last complete war year—1944—58% of the aluminium used for making castings was secondary ; the figures for wrought forms and for other purposes were 29% and 40%, respectively ; the overall average for all applications was 38%. This surely is an achievement of which British industry may well be proud. From the beginning of 1940 to the middle of 1945, 380,000 tons of secondary aluminium was produced in the United Kingdom. This does not exclude that recovered from crashed aircraft.

During the same period, 186,000 tons of virgin aluminium was produced, and 806,000 tons imported. These figures illustrate effectively the necessity for the maximum utilisation of secondary aluminium as a means of conserving foreign exchange during these post-war years.

The importance of secondary aluminium is also well understood in the U.S.A., where the production of this material rose from 54,000 tons in 1939 to 314,000 tons in 1943. These are figures of wartime consumption, but a recent American survey has given 300,000 tons as the expected demand in that country within a few years.

Applications

There can be little doubt that the need for aluminium and the extent of its application will continue to increase in the years to come. One of the factors of pre-war days which tended to limit its use was its unfavourable comparison in price with other materials. To-day, not only are secondary alloys produced in absolute conformity with national specifications, but the price level is lower than it has ever been. It is to be expected, therefore, particularly in the field of general-purpose and unstressed components that considerable numbers ot brass castings will in time be replaced by aluminium, since these alloys have a weight-to-volume ratio one-third that of brass. This applies also, in the same field, to cast iron, where in addition, the ease of production (by diecasting), and saving in freight charges are further considerations. The present heavy demands of the building industries, for example, should provide an excellent opportunity for the substitution of many iron castings by aluminium.

Although considerable quantities of aluminium may be involved in such substitutions, it must be emphasised that, in general, aluminium alloys will be used because of the unique properties which they possess. In all forms of transport, both on sea and land, in the engineering, electrical, chemical and food industries, for cooking and domestic appliances in the home, and in fact, in almost every sphere of human activity there is a need for aluminium. Manufacturers and fabricators of aluminium alloys in this field of application will not only be able to draw upon enlarged facilities for the production of primary aluminium but also the economic advantages of those alloys which are produced from secondary raw material with which a very large proportion of such applications can be satisfactorily met.

New Developments in Hardness Testing

By VINCENT E. LYSAGHT

Wilson Mechanical Instrument Co., Inc., New York, N.Y.

The property of hardness has become of very great importance, not only in the study of metals and alloys, but in the application of these materials, and tests have been devised to measure this property. These tests are based on the resistance to indentation of the materials to be tested. A number of types of hardness testers are in regular use, but the property of hardness is difficult to evaluate. In this article brief reference is made to the Tukon tester and Knoop indenter recently developed.

THE hardness testing of metals by the method of permanent indentation is probably the most commonly employed test in industry to-day. The reason for this is obviously because of the simplicity of the test as carried out in modern testers, and the relatively small cost of hardness testing in comparison to the value of the test. It is a far different problem than when Dr. Brinell first introduced his method. This test was valuable, but as is well known, the test was slow, noticeably marred the work due to the size of the impression, and had limitations on the upper hardness values and sizes of specimens. The Scleroscope certainly speeded up hardness testing, but had limitations which are likewise well known.

The "Rockwell" tester, which could be used with satisfactory results in both shop and laboratory, was rapid, made a small indentation and used a diamond penetrator. It was based on arbitrary values, and made no pretence in being related to load/area or other values. Time has proved the value of the test and its acceptance by industry.

The 136° diamond pyramid test was used by those in laboratories who were not interested in speed, and who liked the flexibility provided by a large number of loads. The results were satisfactory, if one avoided the pitfalls of associating hardness numbers regardless of the applied load, and of considering the sensitivity of the test based on hardness numbers rather than actual measured length of impression.

Such was the status of hardness testing in the early thirties. By this time the metallurgist and testing engineer were well acquainted with the value of the indentation hardness test. These men wanted to extend the test to cover thinner material, nitrided cases, etc. The work could be done to some extent on the Vickers tester, but this would not cover all their requirements. The question of testing these materials in the shop, inspection department, etc., arose, and the superficial hardness tester was developed.

As the metallurgist and engineer began to rely more and more on hardness tests, and even began to seek information relative to the hardness of platings only about 0·001 in. thick, the hardness of metal constituents, hardness of the very cutting edge of tools, and other similar requirements, it became apparent that the depth of indentation would be so shallow that any attempt to develop a direct reading instrument would be hopeless. It would be advisable with such testing to carefully select the spot where the tests could be made, and be able to place the impression exactly on the spot desired. An indenter would have to be designed to produce an extremely shallow penetration, but of sufficient size to be measured accurately. The invention at the National Bureau of Standards in Washington, D.C., of the Knoop indenter by the late Frederick Knoop, of the Bureau, provided an ideal indenter for such work, and the Wilson Mechanical Instrument Company developed the "Tukon" tester for applying light loads to be used with the Knoop indenter.

Fig. 1.—The "Tukon" tester and "Microton" mechanic l stage.

The Knoop indenter is diamond in material, and is ground to a pyramidal form that produces a diamond (rhomb) shape indentation having long and short diagonals of approximately the ratio of 7 to 1. The pyramid shape employed has an included longitudinal angle of 172° 30′ and included transverse angle of 130°.

The "Tukon" tester (Fig. 1) applies loads of from 25–3,600 grms. It differs from the conventional type of hardness tester in that the indenter is not permitted to penetrate into the work under control of the cam or the dash pot. Rather is the piece being tested forced into the indenter until the hardness of the work supports the indenter. This permits the application of the load at a uniform rate and always normal to the surface, if the sample is properly prepared. With this tester the load remains on the work for a fixed length of time slightly in excess of 20 secs. The entire test cycle is automatic. The machine is designed for operation with 60 cycle, 110 volt a.c., but it can also be adapted for 50-cycle, 110-volt a.c. operation.

When testing steel of "Rockwell" hardness C-63, the length of the indentation with the Knoop indenter under a 100-grm. load is about 40 microns. When the load is reduced to 25 grms., the length is about 20

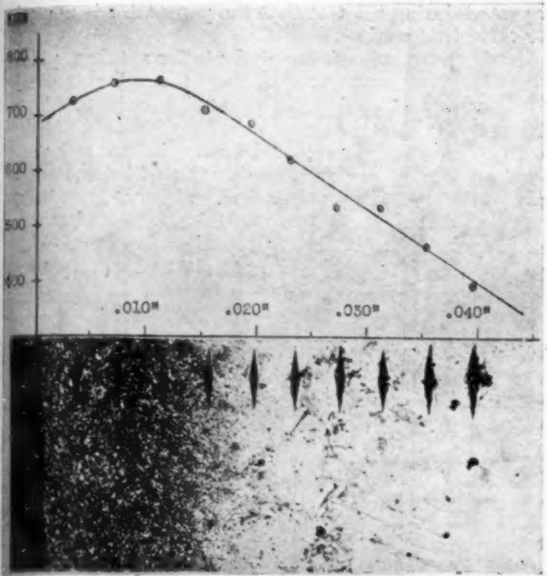


Photo. by R. H. Jacoby.

Fig. 2.—Knoop hardness gradient through a carburised case. Load 1,000 grams. × 100.

Reduced to approx. ⅞ linear.

microns. The depths are about 3 and 1 microns, respectively. The 136° diamond pyramid indenter, on the other hand, has a depth of indentation equal to about ⅐ the diagonal. This indicates the size of work which may be tested.

It is possible to locate an impression to better than 10 microns of the desired area with the specially-designed " Microton " mechanical stage.

The length of the indentation may be read to ±1 micron with dry objective lens and magnification of about 500. With experienced operators, properly-prepared samples, proper lighting, etc., it is frequently possible to read to ±0·5 microns.

The " Tukon " tester and Knoop indenter may be used to test both metallic and non-metallic materials, and the use of the instrument for testing metallic materials has been described in detail elsewhere.[1] This tester and indenter and their use for nonmetallic materials ranging from plastics to diamond, are described in *A.S.T.M. Bulletin*, January, 1946.

There are so many varied applications in industry for this new tester and indenter that it would be an almost impossible task to enumerate and to describe them, but their use in the testing of metals and alloys may be conveniently grouped in a few general classes, a brief description of which will be of interest.

One such important class is testing surface hardness of chromium plate, cyanide cases, thin nitrided cases, etc. With respect to hardness determinations of properly-prepared surfaces the problem is essentially the same in each case. It has been possible to measure the hardness of chrome plates 0·0005 in. in thickness without any apparent effect of the base metal. Similar determinations may be made in cyanide cases, thin nitrided cases, etc.

Chromium plates are generally tested with a load of 100 grms., and the hardness range varies from about 850–1,050 Knoop hardness numbers. Variations occur due to types of solution and rates of platings. Values higher than 1,200 (100-grm. load) have been observed under certain conditions.

Closely related to the testing of superficially-hardened surfaces referred to above is the testing of heavier cases and surface testing for decarburisation. Fig. 2 represents the Knoop hardness gradient through a carburised case using a load of 1,000 grms. Decarburised layers may be investigated in the same manner with equally satisfactory results.

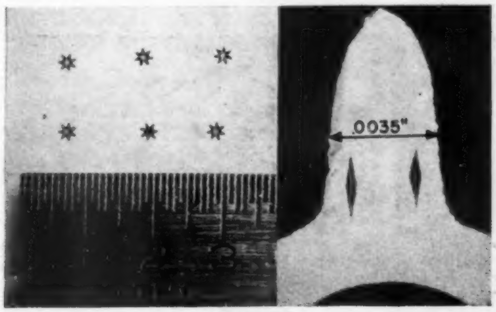


Fig. 3a.—Left : Timepiece minute pinions. × 6. Right : Knoop indentations made with a load of 300 grams on one side of the teeth. × 250.

Reduced to approx. ⅞ linear.

Small precision parts such as are to be found in timepieces are an excellent example of the usefulness of the " Tukon " tester. Fig. 3a shows several small minute pinions 0·0288 in. in diameter together with an enlargement of one of the teeth only 0·0035 in. in width, in which two indentations have been made with a load of 300 grms. Fig. 3b represents pallet spindles in which tests have been made in the pivots which are only 0·010 in. long and 0·0049 in. in diameter. These photographs were taken at the laboratories of the Hamilton Watch Company, where the " Tukon " tester and Knoop indenter are used for control work.

The testing of metal constituents is still another general class of work which is being studied. Fig. 4 shows a Knoop impression made with a load of 100 grms. in mottled iron. The hardness of the pearlite is 300 Knoop numbers, whereas the iron carbide is 1168 Knoop hardness numbers.

From the above it becomes apparent that another class of materials which may be tested is thin sheet metal. Sheet metal even in very soft condition may be tested down to less than 0·002 in. in thickness. The sheet must have a good surface finish, and be flat so as to be normal to the indenter. Bi-metallic strips, fine wire and flat wire may be tested on the " Tukon " tester. Round wire is mounted and given a metallographic polish on either the transverse or longitudinal section.

Knoop indentations may be spaced at very close intervals due to the shape of the indenter, and this is advantageous in studying change in hardness over small areas. For example, in checking the hardness of heat-affected zones in welding, indentations may be spaced at 0·004 in. intervals, thus permitting over 200 impressions in a 1-in. area.

Although this new tester was developed for use with the Knoop indenter, it may also be used with the 136° diamond pyramid indenter, and, for certain investiga-

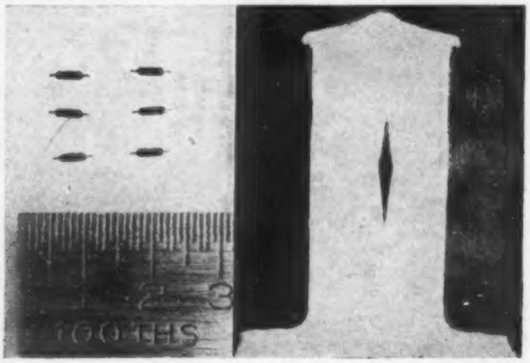
1 " Microhardness Testing of Materials," by V. E. Lysaght. *Materials and Methods* (formerly *Metals and Alloys*), Oct., 1945.

tions, it may be advantageous to use the square base pyramid. Fig. 5 shows impressions in pearlite under a load of 25 grms. giving a diamond pyramid hardness value of 217.

Fig. 6 is a conversion chart[2] showing the relation between "Rockwell" C scale and Knoop hardness numbers using a load of 500 grms. Such a conversion chart is valuable in acquainting the user of Knoop numbers with a more familiar scale. It should be used for general information purposes only, and then with caution, as Knoop numbers vary with applied load. For example, values obtained with a load of 100 grms. are not necessarily the same as values obtained with 1,000 grms. The Knoop hardness number by the very nature of the indenter is limited in its use by the following considerations. It is necessary that the surface being tested be properly prepared. The sample must be lapped plane, and be free from scratches, and so supported during the test that the penetrator is normal to the testing surface.

Elastic recovery of the indentations takes place chiefly in the transverse rather than longitudinal direction, and, therefore, in measuring only the long diagonal, the Knoop hardness number is based chiefly on the unrecovered projected area. Recovered projected areas may be determined by an added measurement of the short diagonal—a field which has been little investigated to date. However, D. R. Tate[3] and others have shown that the Knoop number increased with decreasing loads, probably due to elastic recovery to a certain degree in the long diagonal. Therefore, the Knoop hardness number is dependent upon the applied load which should always be specified.

The test is relatively new, and metallurgists and scientists are offered a method of indentation hardness testing making a minute impression under carefully-controlled conditions with a high-precision indenter requiring optical measurement of the indentation.



Reduced to approx. ¾ linear.

Fig. 3b.—Left: Pallet spindles, with pivots 0.010 in. long, and 0.0049 in. in diameter.
Right: Knoop indentation made with load of 500 grams on the spindle pivot. × 250.

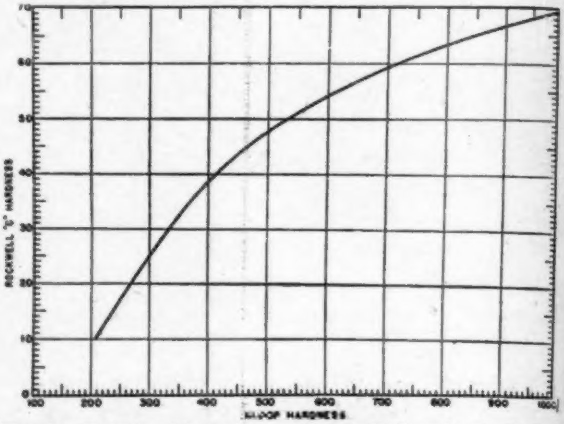


Fig. 6.—Relationship between Rockwell C-scale numbers and Knoop numbers. Load 500 grams.

2 "Induction Hardening of Plain Carbon Steels," by D. L. Martin and Florence E. Wiley. Trans., American Society for Metals, vol. 34, 1945.

3 "A Comparison of Microhardness Indentation Tests," by Douglas R. Tate. Trans., American Society for Metals, vol. 35, 1945.

Fig. 4.—Knoop indentations in mottled iron. Load 100 grams. × 500.
Pearlite 300 K H N. Iron carbide 1168 K H N.

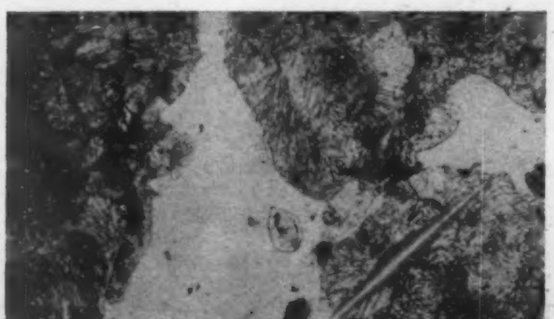
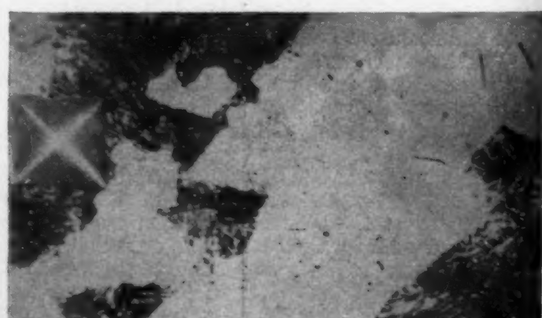


Fig. 5.—136° diamond pyramid indentations in pearlite. Load 25 grams. × 1,000.
Diamond pyramid hardness number 217.

Photos. by R. H. Jacoby.



A Metallurgical Study of German Aircraft Engine and Airframe Parts

This report constitutes a summary of further data, resulting from the metallurgical examination of German aircraft engine and airframe parts by the Aero-Components Sub-Committee of the Technical Advisory Committee of the Special Alloy Steel Committee formed for that purpose.

The types examined represent a comprehensive range of various types of German aircraft which have fallen into the hands of the R.A.F. from 1942 onwards.

The principal object of these investigations was to obtain data on the types and quality of materials used, methods of manufacture, efficiency of the heat-treatment to which the parts have been submitted, together with any other information which might prove of value, as, for example, details of the finish. Further, the influence of restrictions, due to our blockade, on German procedure and selection of materials was kept in mind. Attention was given chiefly to engine parts but a number of airframe and miscellaneous components were included. Special features concerning design had been noted in certain instances, but these were not the primary object of the investigations. The Sub-Committee responsible for these investigations and for this report comprise; Mr. S. Barraclough, United Steel Companies, Ltd.; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, the English Steel Corporation, Ltd.; Mr. W. J. Dawson, (Chairman), Hadfields, Ltd.; Dr. R. Genders, M.B.E., S.T.A.M., Ministry of Supply; Mr. H. J. Hipkins, Royal Aircraft Establishment; Mr. N. H. Mason, R.A.E., Farnborough; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Mr. L. Rotherham, Thos. Firth and John Brown, Ltd.; Dr. H. Sutton, Ministry of Aircraft Production; Miss M. K. Walshaw, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out as a continuation of the data already published. It has been carried out meticulously. Naturally in this Report no comparisons are made with corresponding parts in British and American Aircraft, neither are certain aspects which our investigations have shown to be open to criticism emphasised.*

Section XIII.—Airframe Components

A. Engine Mountings

ENGINE mountings and bearers from four types of aircraft have been examined, as follows:

1. Focke Wulf 190 A-2 aircraft, BMW 801 engine (Item 177).
2. Messerschmitt 210 aircraft, D.B. 601 F engine (Item 272).
3. Dornier 217 aircraft, D.B. 603 engine (Item 297), and
4. Heinkel 177 aircraft, D.B. 605 engine (Item 293).

1. *Focke Wulf 190 A-2 aircraft, BMW 801 engine (Item 177).*

The mounting in this aircraft consisted of a hollow, hexagonal ring of box section, attached to the fuselage by a triangulated tubular structure. The ring was made by welding together steel channel sections, and formed a reservoir for the hydraulic fluid used in the automatic engine-control unit. Approximately half the complete ring was received for examination, and this portion is shown in Fig. 1. Four separate pieces of sheet had been used in the construction of the semi-ring, three of these being 2·3% manganese steel

Fig. 1.—Part of mounting ring for BMW 801 engine, F.W. 190 aircraft.

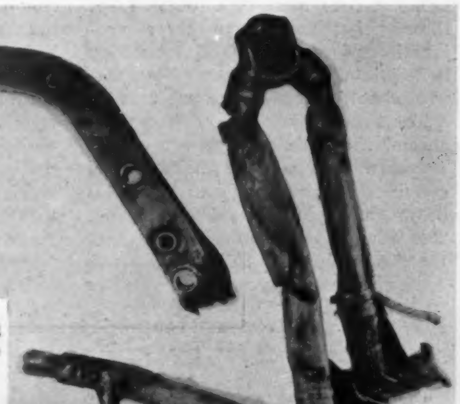


Fig. 2.—Part of tubular mounting, BMW 801 engine F.W. 190 aircraft.

containing 0·2% carbon, and the other being a 1% chromium-molybdenum steel. The diamond pyramid hardness of the four sheets showed no great variation at 217–240. The sheet materials were probably in the as-rolled condition, with no heat-treatment, except possibly a stress-relieving treatment after welding.

A number of tubular bushes and pipe fittings had been inserted in the ring, and welded into position. A steel bolt was fitted in one bush, and a pawl in another. These parts had been machined from tube or bar stock, and the types of material used were as in table on next page.

Only a portion of the tubular structure connecting the ring to the fuselage was available at the time the examination was made. This was

*"A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts," 1943, The Kennedy Press, Limited.

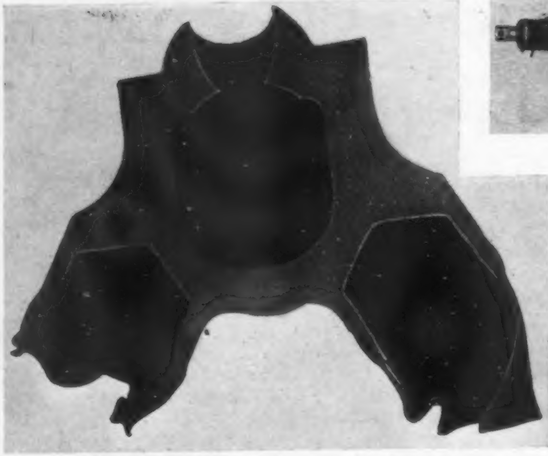


Fig. 3.—Section through recessed vee-junction piece, BMW tubular mounting from F.W. 190 aircraft.

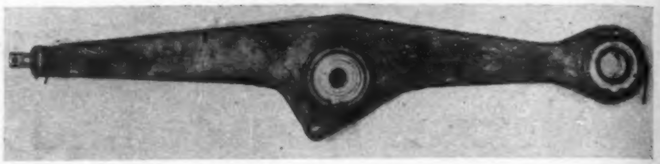


Fig. 5.—Engine bearer from Me 210 aircraft DB 601 F. engine.

Component	Type of Steel	D.P. Hardness
Tubular Bush	1% Cr-Mo	241–255
Pipe Fitting ..	2·3% Mn.	277
Bolt	1·1% Mn, 0·86% Cr, 0·16% V	300
Pawl	0·15% C, 8·9% Mn, 17·9% Cr..	248

severely damaged, and is shown in Fig. 2. It consisted of three lengths of tube (14, 16 and 19 gauge) and a broken-off fragment of a fourth tube, these being welded to three vee-junction pieces, machined to act as ball joints. A fork coupling was welded to the free end of one tube.

The tubes had been made from 1% chromium-molybdenum steel. The 19-gauge tube was in the annealed condition; the others had been cold drawn and possibly stress relieved. The diamond pyramid hardness of the three tubes was 217–229.

The recessed vee-junction piece shown at the bottom of Fig. 2 was attached to the fuselage front frame, and had been made as a drop stamping in 1% chromium-molybdenum steel, heat-treated to possess a hardness of 302–311. An etched section through this part is shown in Fig. 3. The two plain vee-junction pieces visible in Fig. 1 formed attachment points for the mounting ring, and had been made as drop stampings in a steel containing 1·1% manganese, 0·65–0·85% chromium and 0·10% vanadium, the hardness being 269–302. An etched section through one of these junction pieces is shown in Fig. 4. A similar manganese-chromium-vanadium steel had been used for the forked coupling shown in Fig. 1. This had been machined from bar stock, and had a D.P. hardness of 235.

The cleanness of the steels used in the ring and tubular structure was comparable with that of British basic electric steel. All welds had been well made, and there was no evidence of any heat-treatment subsequent to welding.

2. *Messerschmitt* 210 *Aircraft, D.B.* 601 *F Engine* (*Item* 272).

In this aircraft, each engine was supported by two bearers, one of which is shown in Fig. 5. The design was similar to that of the forged magnesium alloy bearers commonly used for liquid cooled engines in earlier types of German aircraft, but in this case, each bearer was built up from four main formed steel sheet sections welded longitudinally down the narrow faces and transversely across the centre. At one end was a forked attachment fitting, normally connected to the bottom of the engine bulkhead. An etched section through the fork attachment is shown in Fig. 6. At the opposite end and at the centre were flexible bearings for carrying the engine. On one side of the centre bearing an extension piece was formed from two pieces of welded sheet; this carried a lug for a tubular tie-rod (not examined) attached to the top of the bulkhead.

The flexible bearings were fitted into tubular steel inserts welded into the main bearer, and were held

Fig. 4.—Section through plain vee-junction piece, BMW tubular mounting from F.W. 190 aircraft.

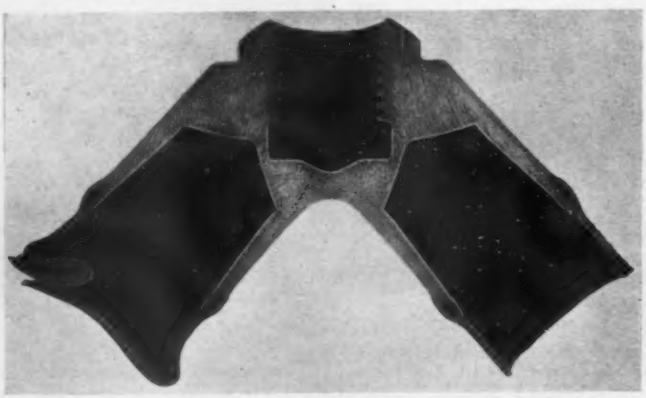


Fig. 6.—Section through fork attachment, Me 210 engine bearer.

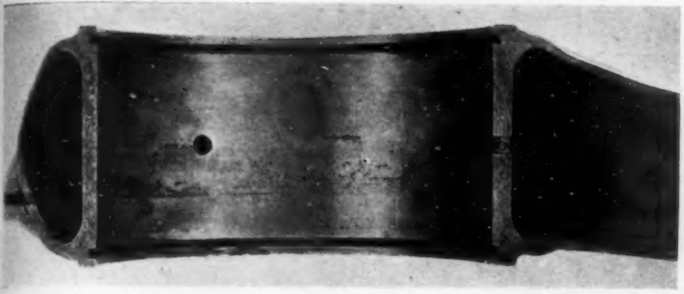


Fig. 7.—Insert for flexible bearing, Me 210 engine bearer.

by spring retaining rings. An etched section through the insert carrying the end bearing is shown in Fig. 7; this part had been made as an upset forging.

The centre flexible bearing is shown sectioned in position in the bearer in Fig. 8, and dismantled in Fig. 9. It was built up from two sets of light-alloy discs of differing internal and external diameters moulded alternately into a rubber-like substance. Light-alloy rings were fitted to the inner and outer grooves so formed, the inner rings being cut into four segments. A central light-alloy tube was fitted inside the inner rings.

With the exception of the actual fork, all the materials used in the construction of the bearer approximated to the following composition:

Carbon	0·22—0·28%
Manganese	1·0%
Chromium	0·7%
Vanadium	0·2%

The tensile strengths and Brinell hardnesses of the four main sheet portions showed appreciable variation, and were 54·7–70·6 tons/ sq. in., and 269–321, respectively. The fork had been machined from bar of the following approximate composition:

Carbon	0·35%
Manganese	0·75%
Chromium	2·25%
Vanadium	0·2 %

It had been hardened and tempered to possess a D.P. hardness of 340–356. The spring retaining rings for the flexible bearings had been made from 0·75% carbon steel, oil hardened to 488–502 D.P.H.

The various non-ferrous discs and rings in the flexible bearings were of similar analysis, and were of duralumin type containing 1·2–1·8% magnesium.

The normal as-welded structure was not seen at any of the welds, and the complete component—apart from the fork—had evidently been heat-treated after welding. The D.P. hardness values obtained on the numerous welds sectioned showed considerable scatter in the range 296–393. The part had probably been heated to approximately 850° C., but oil quenched from a temperature of about 780–790° C. The slight delay in quenching would account for the differences in hardness with varying section. The final tempering temperature was probably of the order of 450° C.

3. *Dornier* 217 *Aircraft, DB* 603 *Engine* (*Item* 297).

A bearer from this aircraft is shown in Fig. 10. As in the case of the Me 210 bearer, it had been built up by welding together four main sheet sections. Flexible bearings were inserted at one end and at the centre, and the other end terminated in a universal joint attachment. The flexible bearings were identical with those in the Me 210 bearer, except that they were locked with threaded light-alloy rings instead of steel spring rings. A section through the insert for the centre bearing is shown in Fig. 11. The presence of heat-affected zones at the welds shows that this part is in the as-welded condition.

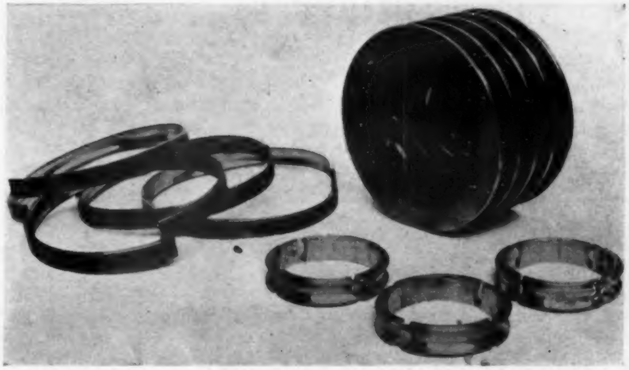


Fig. 9.—Dismantled flexible bearing, Me. 210 engine bearer.

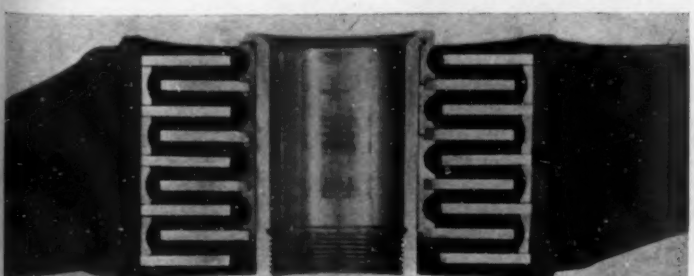


Fig. 8.—Section through flexible bearing Me 210 engine bearer.

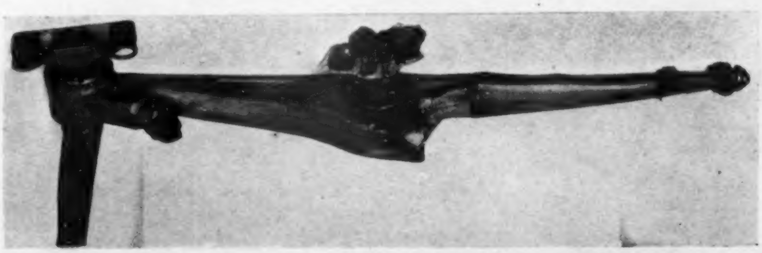


Fig. 10.—Engine bearer from Do. 217 aircraft, DB 603 engine.

The universal joint was screwed into the main body. It is shown dis-mantled in Fig. 12. (Without locking nut and independent coupling.)

Two attachments, shown in Fig. 10, were fitted in the two flexible bearings

Fig. 11.—Insert for flexible bearing, Do. 217 engine bearer.

by means of taper-bored light-alloy sleeves. These attachments are shown sectioned in Figs. 13 (centre bearing) and 14 (end bearing). The centre attachment had been made as a hollow forging, and the end attachment had been built up by welding together a forged outer shell and a hollow taper shaft machined from bar. Unlike the main assembly, the welded attachment had been heat-treated after welding.

The compositions of the individual parts of the bearer fall into two main groups, the sheets with one exception containing essentially carbon 0·2%, manganese 1·6–1·9%, and the majority of the remaining parts, including one sheet, containing approximately carbon 0·3%, manganese 1·1%, chromium 0·55–1·0% and vanadium 0·15%. A 2½% chromium-vanadium steel had been used for the threaded stem of the universal joint, and a normal carbon-chromium steel for the hollow bearing.

The sheets were of variable hardness (equivalent to 50–57 tons/sq. in. tensile strength), and were in the softened and cold-rolled condition. The other parts were mostly hardened and tempered.

Fig. 12.—Part of universal joint attachment. Do. 217 bearer.

4. *Heinkel* 177 *Aircraft, D.B.* 605 *Engine* (*Item* 293).

The three portions of the mounting examined are shown in Fig. 15, and

consisted of part of a tube, a formed plate fitting carrying a bolt, and a universal joint. The tube had been made from 1% chromium-molybdenum steel, and had welded to it a short, threaded extension piece made from a steel containing 1·2% manganese, 0·7% chromium, and 0·1% vanadium. The tube assembly had been heat-treated after welding. The D.P. hardness of the tube was 296–310, and of the extension, 338–340.

The joint was of the ball-and-socket type, fastened with a threaded sleeve. The four parts comprising the joint had been machined from manganese-chromium steel bar containing 0·65–1·2% manganese, 0·8–2·4% chromium and 0·25–0·30% carbon. The ball portion and locking nut contained 0·1% molybdenum, and the other two parts up to 0·2% vanadium.

The plate fitting and bolt contained approximately 0·3% carbon, 2½% chromium, 0·1% molybdenum, and 0·2% vanadium. Both had been hardened and tempered, the D.P. hardness of the plate being 284–292, and of the bolt, 356. The bolt had been machined from bar. The microstructure at the top and bottom of the eye in the plate showed no deformation, and had the appearance locally of a casting. The part had probably been made from a casting of simple form, forged where the section was reduced, and finished as a drop stamping.

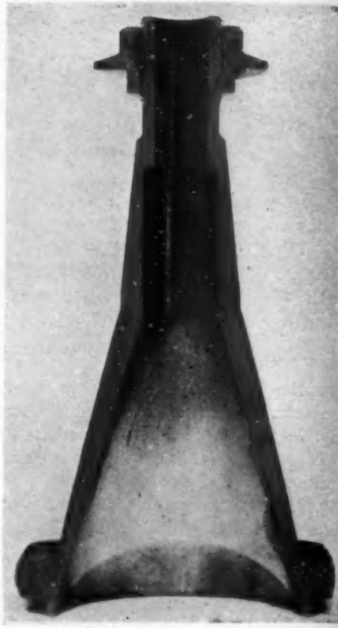


Fig. 13. Section through centre bearer attachment Do. 217 engine bearer.

General Observations

The steels used for the main parts of the four types of engine mounting

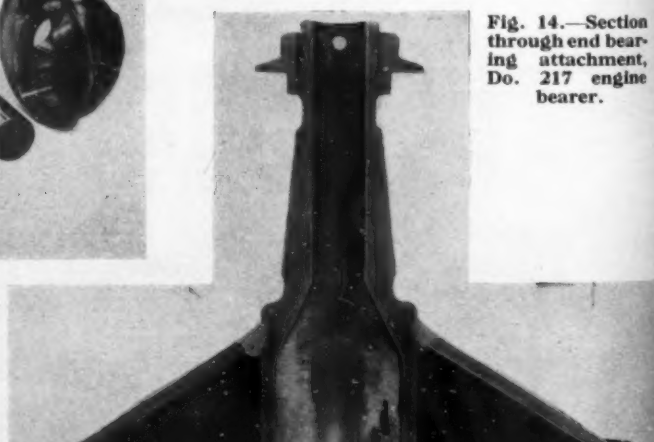


Fig. 14.—Section through end bearing attachment, Do. 217 engine bearer.

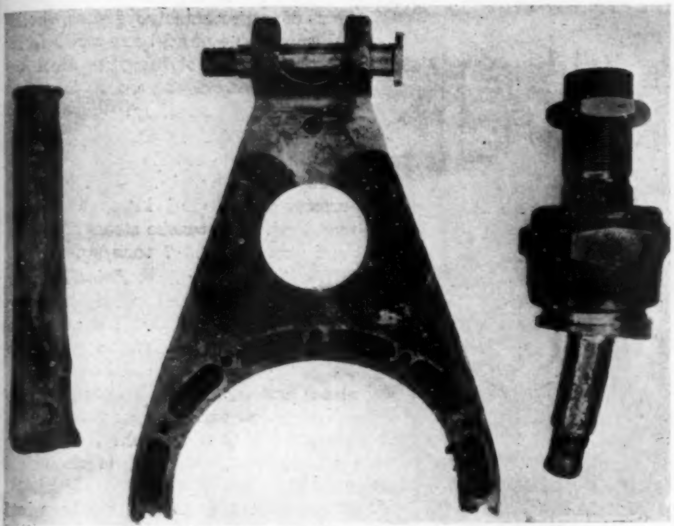


Fig. 15.—Parts of He. 177 engine mounting.

described were of basic electric quality. The outer surfaces of the main assemblies of Items 177, 272, and 297, and of the tube in Item 293, had been shot or sand blasted before painting. The many welds examined had been well made; the Me 210 bearer, one fitting from the Do. 217 bearer, and the tube from the He 177 mounting had been heat-treated after welding. The other welded parts had been put into service in the as-welded condition.

B. Wing Attachment Fittings

Joint fittings from the following air-

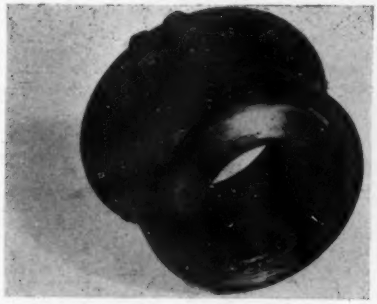


Fig. 17.—Me. 210 wing joint fitting, leading edge, inner wing.

craft have been examined:

1. Messerschmitt 210 (Item 282);
2. Dornier 217 E (Item 285), and
3. Dornier 217 K (Item 299).

1. *Me 210 Wing Attachment Fittings.* The outer wings of this aircraft are connected to the centre section at the spar and at the leading edge. A spar attachment fitting is shown in Fig. 16 (inner wing). The leading edge connection was a Junkers ball-type joint; the two halves are shown in Figs. 17 (inner wing) and 18 (outer wing). Fig. 19 shows detailed drawings of the ball-joint parts (A, B, C, D,

Fig. 16.—Me. 210 wing spar joint fitting, inner wing.

Fig. 18.-Me. 210 wing joint fitting, leading edge, outer wing.

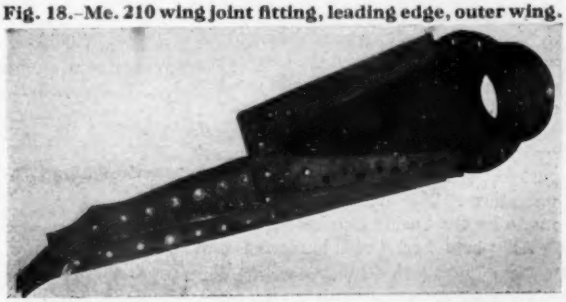


TABLE I—CHEMICAL COMPOSITIONS, ETC., OF WING JOINT FITTINGS.

Item No.	Component	Part No.	Composition % C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	Grain Size	Brinell Hardness	Remarks
282	Me 210 wing attachment fittings:—														
	Spar joint fitting, inner wing ..	—	0·37	0·24	0·58	0·005	0·018	—	2·8	Nil	0·14	0·09	8	357–364	Forging
	Do. do. outer wing ..	—	0·34	0·22	0·68	0·007	0·010	0·30	2·6	Nil	0·17	0·13	8	351–375	Forging
	Leading edge joint, inner wing ..	A	0·30	0·30	1·2	0·005	0·008	Nil	0·7	Nil	0·09	0·12	5–6	277	Machined from bar
		B	0·28	0·36	0·61	0·005	0·017	0·38	1·0	0·11	Nil	0·15	5–6	311	Ditto
		C	0·27	0·34	0·60	0·005	0·017	0·34	1·0	0·09	Nil	0·15	5	302	
		D	0·27	0·29	0·55	0·008	0·010	0·34	1·0	0·11	Nil	0·15	6	298–302	Machined from bar
	Do. do. Bolt ..	—	—	0·34	0·65	—	—	Nil	1·3	0·15	Nil	0·05	—	—	
	Nut ..	—	—	0·24	0·76	—	—	Nil	0·14	Nil	Nil	—	—	—	
	Washer ..	—	—	0·23	0·34	—	—	Nil	0·11	Nil	Nil	—	—	—	
	Leading edge joint, outer wing ..	E	0·28	0·24	1·2	0·010	0·011	Nil	0·7	Nil	0·08	0·16	5 & 7	293–302	Upset
285	Dornier 217 E attachment fittings:—														
	Top flange attachment—plate ..	A2/1	0·29	0·46	0·66	0·009	0·027	0·08	0·96	0·20	<0·1	0·12	7	340	Casting
	plate ..	A2/2	0·33	0·27	0·56	0·007	0·027	0·06	0·91	0·13	0·21	0·18	7–8	291–302	Casting
	bolt ..	A2	0·25	0·28	0·64	0·012	0·017	0·19	0·98	0·19	<0·1	0·12	—	311	
	nut ..	A2	0·23	0·28	0·85	0·011	0·013	0·30	1·07	0·23	<0·1	—	—	311	
	Bottom flange attachment—plate ..	B1/2	0·30	0·39	0·65	0·006	0·019	0·08	0·95	0·14	<0·1	0·15	7	273–293	Casting
	bolt ..	B2	0·24	0·27	0·68	0·012	0·024	0·17	0·96	0·21	<0·1	0·13	—	286	
	nut ..	B1	0·23	0·20	0·62	0·014	0·012	0·02	1·14	0·21	<0·1	0·05	—	351	
299	Dornier 217K attachment fittings:—														
	Plate ..	A1	0·28	0·33	0·65	0·006	0·021	0·04	1·05	0·17	Nil	0·11	6	269–321	Casting. Zinc coated
	Plate ..	A2	0·27	0·33	1·54	0·008	0·018	Tce.	0·09	0·02	0·08	0·11	6	269–302	Ditto
	Bolt ..	1	0·25	0·16	0·63	0·014	0·021	Tce.	2·33	0·01	0·17	0·10	—	351	
	Nut ..	1	0·26	0·32	0·96	0·010	0·018	0·05	0·83	0·01	0·11	0·15	—	260	Zinc coated
	Washer	1	0·27	0·32	1·05	0·008	0·016	0·02	0·77	0·01	0·11	0·21	—	223	Ditto

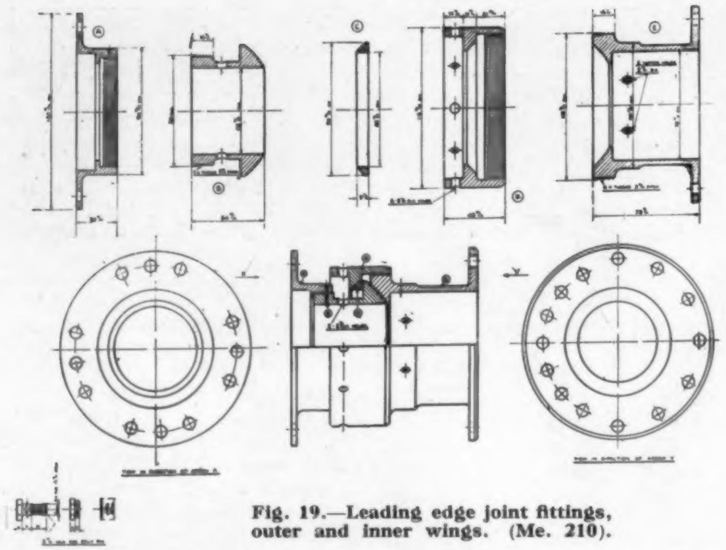


Fig. 19.—Leading edge joint fittings, outer and inner wings. (Me. 210).

inner wing component ; E, outer wing component), and of the assembly.

All the components had been painted except on bearing or threaded surfaces. After removal of the paint, the spar fittings were seen to have been smooth ground, whereas the ball-joint parts had been smooth turned. The compositions of the various parts are given in Table I. The two spar fittings had been made from 2½% chromium-vanadium steel. Three parts of the leading edge ball joint had been made from 1% chromium-molybdenum steel, and two from a steel containing 1¼% manganese, 0·7% chromium and 0·1% vanadium. The steels used had been made by the basic electric-arc process.

All parts had been hardened and tempered. The results of tensile and Izod tests on the spar-joint parts, and tensometer tensile tests on the leading edge ball-joint parts were as table above:

	Spar Joint Fittings		Leading Edge Joint Fitting Parts		
	(1)	(2)	(B)	(D)	(E)
Maximum Stress, T/in.	75·6	75·5	65·4	61·0	63·5
Elongation, %	18½	17	22	20	18½
Izod, Ft./lb.	28, 25, 25	15, 17, 17	—	—	—

Examination of the grain flow in the various parts showed that the spar fittings had been made as forgings. Item A, B and D of the leading-edge joint (see Fig. 19) had been machined from bar, but Item E had received a certain amount of upsetting.

2. *Do. 217 E Wing Spar Joint Fittings.*

In this aircraft, the junction of the outer and inner wing spars is effected by steel bolts passing through pairs of steel stiffening plates attached to each side of the four spar flanges. Two plates and a connecting bolt from a joint in a lower spar flange are shown in Fig. 20. The plates in the upper flange joints are of slightly different design, and the bolt is considerably smaller.

Except for the bearing surfaces of the bolts, all parts had been painted. The surfaces of the plates were scale free, and appeared to have been sand blasted. Table I gives the compositions of representative plates, bolts and nuts. They had been made from 1% chromium-molybdenum steel of electric-arc manufacture, one plate containing 0·2% vanadium.

The plates had been made as castings and possessed tensile strengths of 62–69·6 tons/sq. in. Evidence of porosity was found in each section examined. The tensile strength of the bolts was 61·6–63·7 tons/sq. in.

3. *Do 217K Wing Spar Joint Fittings*

This aircraft has a somewhat greater wing span than the Do. 217 E, and there are obvious slight differences in the design of the plates and bolts. Four plates and two bolts, representing the complete joint in one spar flange, were examined. The assembly, including portions of the flange, is shown in Fig. 21.

The plates, nuts and washers had been zinc plated, and the plates had been painted. The bolts had a smooth-ground finish except on the large-diameter head, which retained the rolled surface of the original bar stock.

The plates had been made as castings, two of them in the 1% chromium-molybdenum steel used for the Do. 217 E plates. For the other two a 1¼–1½% manganese-vanadium steel had been employed. Both types had been heat-treated to a 55–65 tons tensile range, the higher value being obtained in the thinnest portions of the castings. The bolts had been machined from 2½% chromium-vanadium steel bar stock, and heat-treated to 70 tons tensile strength. The compositions of typical plates, bolts, etc., from the assembly are given in Table I.

Fig. 20.—Do. 217 E wing spar joint plates.

Fig. 21.—Do. 217K wing spar joint.

THE Report presented at the first Annual Meeting of the Microchemistry Group showed that considerable progress has been made in a number of directions. The policy of holding meetings at various centres throughout the country, which is one of the noteworthy decisions taken at an early stage in the Group's formation, can be correlated in a possibly illuminating fashion with a point which came to light at the Annual Meeting and reading of papers which followed it. Of three meetings held in Manchester, Newcastle and London, that in London, which one would have expected to be the best attended, drew noticeably fewer members. This should not be the case; the more since it was an Annual Meeting, and a Society usually flourishes in direct relation to the interest shown in its running by the members at large. It must be concluded that either members who would have had some distance to come were unable to obtain accommodation in London for the meeting, or else interest in microchemistry is surprisingly less of interest to chemists in the London area than to those of the provinces. It would be illuminating, perhaps, to know what proportion of the 160 members now on the roll reside within easy travelling distance of London. However that may be, it should be stressed for the benefit of members that they may in the long run obtain as much from attendance at a business meeting as from attendance at a simple reading of papers.

The Potentiometric Micro-determination of pH.

By J. T. Stock and M. A. Fill

Hydrogen, quinhydrone and glass electrodes may all be adapted to the potentiometric determination of pH on small samples. Various electrodes devised for this purpose are described in the following article.

OWING to the rapidity and accuracy with which measurements may be carried out, the determination of pH by the potentiometric method is of the greatest importance. A few introductory remarks may be made in connection with the principles involved, but for a full discussion the reader is referred to the numerous specialist monographs.[1]

When an electrode of a given metal is dipped into a solution containing its own ions, a definite difference of potential is set up between the electrode and the solution. If the electrode reaction is reversible, then, at ordinary temperature (17° C.), this potential difference π is given by

$$\pi = \pi_0 + \frac{0{\cdot}058}{n} \log a \quad \ldots \quad (1)$$

where π_0 is constant for a given metal, while n and a are respectively the valency and the activity of the ions under consideration.

The potential of a single electrode with respect to a solution cannot be measured. However, two electrodes, each dipping into a solution, may be combined to form a voltaic cell, the e.m.f. of which is readily measureable. It is the usual practice to use as the second "half cell" an electrode-solution system of fixed potential, termed a *standard*—or *reference electrode*. Examples are the calomel electrode and the silver—silver chloride electrode[1]. To minimise the "junction potential," which would otherwise be set up, the solutions of the two electrode systems are usually connected by a "salt bridge," often consisting of saturated potassium chloride solution, or of an agar jelly saturated with the same salt. The arrangement is depicted in Fig. 1. The e.m.f., E, of the cell may then be measured, usually by the Poggendorf compensation method,[1] and is given by

$$E = \pi - \pi_s \quad \ldots \quad (2)$$

where π_s is the potential of the reference electrode. Paying due regard to the signs of the potentials, π may then be calculated.

A piece of platinum coated with platinum black and saturated with gaseous hydrogen acts as if it were

1 See, for example, W. M. Clark, "The Determination of Hydrogen Ions," London, 1928; H. T. S. Britton, "Hydrogen Ions," 2 Vols., London, 1942; M. Dole, "The Glass Electrode," New York, 1941; H. J. S. Sand, "Electrochemistry and Electrochemical Analysis," 3 Vols., London, 1939; S. Glasstone, "The Electrochemistry of Solutions," London, 1937.

composed entirely of the latter element. If it is dipped into a solution containing hydrogen ions, the potential is given by equation (1) n and π_0 being put equal to unity and to zero respectively. However, when determined potentiometrically[2]

$$\mathrm{pH} = -\log a_H$$

Hence

$$-E = \pi_n + 0{\cdot}058\ \mathrm{pH} \quad .. \quad .. \quad .. \quad (3)$$

Accordingly, the e.m.f. of the cell formed by combination with a reference electrode affords a measure of the pH of the solution into which the hydrogen electrode dips.

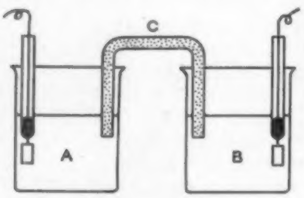


Fig. 1.—Schematic Arrangement of Voltaic Cell. A—Test Solution and Electrode. B—Reference Electrode System. C—Salt Bridge.

The hydrogen electrode has many disadvantages,[1] such as the necessity for a supply of pure hydrogen, the sluggishness with which it attains a steady potential and the ease with which it is " poisoned." It is, however, the ultimate standard by which all other electrodes are calibrated and, unlike these, exhibits no error in ordinary alkaline solutions of high pH.

Various types of micro-hydrogen electrode have been described. That shown in Fig. 2A is suitable for examining samples of about 1 ml. in volume.[3] The desirable condition that the electrode surface should be exposed intermittently to the solution and to the gas, while at the same time maintaining good electrical connection with the solution, is achieved in an ingenious manner. The platinised platinum electrode is of wire form, and is pointed at the lower end. As each hydrogen bubble rises from the bottom of the vessel, it is pierced

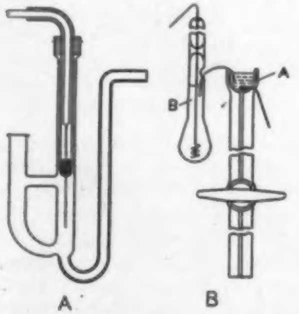


Fig. 2.—Micro Hydrogen Electrodes. A—Lockwood. B—Frediani.

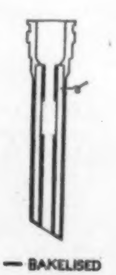


Fig. 3.—Mikawa Micro Quinhydrone Electrode.

and in rising comes into contact with the whole length of the electrode. Owing to the shape of the vessel, passage of hydrogen causes a slight circulating effect in the liquid. A calomel reference electrode with a fine outlet dips into the open tube and enables electrical connections to be completed.

Fig. 2B shows a hydrogen electrode for volumes of liquid of from 5 to 60 cubic millimetres.[4] The upper end of the 1-mm. bore tube is expanded into a little cup, A, having a maximum capacity of 0·1 ml. The electrode is made by fusing the end of a 3-cm. length of No. 20 platinum wire to form a small ball. This is flattened into a disc 3-mm. in diameter, and the wire is sealed into the side of the cup as shown. The edge of the disc should be in line with the bore of the capillary. After platinising, the electrode assembly is ready for use. The sample is placed in the cup, and connection is made to a bulb-type calomel electrode B by means of a short length of cotton or similar thread. On introducing hydrogen at the lower end of the capillary and opening the stopcock, the liquid is blown up into contact with the thread and the electrode. With hydrogen bubbles forming at the rate of 30 per minute, equilibrium is rapidly established.

Other micro-hydrogen electrodes have been described by Dorfmann[5] and by Löbering.[6] The apparatus described by the latter worker is of the enclosed type, and allows samples having a volume less than 0·1 of a ml. to be examined. The electrode vessel stands partially immersed in potassium chloride solution, which serves the dual purpose of junction liquid and of a seal to prevent ingress of air.

The oxidation-reduction potentials of many systems of organic compounds depend on the pH of the solution in which they are dissolved,[1] affording a possible means of determining pH without the use of hydrogen. Biilmann[7] showed that the molecular compound quinhydrone could be used for this purpose. In practice, sufficient quinhydrone is added to saturate the test solution. An inert electrode, usually of bright platinum or gold, is inserted, and the potential, from which the pH of the solution may be readily calculated, is measured with the aid of a reference electrode, as described.

Though not applicable to solutions having a pH higher than about 8, the quinhydrone electrode possesses the supreme advantage of simplicity, both in construction and in operation. Accordingly, its possibilities have been explored in many directions, including its application to the micro scale.

The micro-quinhydrone electrode shown in Fig. 3 allows the pH of samples of liquid as small as 0·01 ml. to be determined.[8] The electrode is a thin gold tube having an inside diameter of about 1 mm. With the exception of the middle third of the bore, the electrode is coated with bakelite varnish, which is hardened by baking. The exposed part of the bore is gold-plated; the plating has a long life. The electrode may be attached to a syringe by means of a rubber nipple, thus permitting the sample to be drawn in when required. To prepare the sample for examination, a little finely powdered quinhydrone is placed on a paraffined watch glass. A drop of the liquid to be tested is then added and caused to roll round until well covered with quinhydrone. It is then drawn into the electrode, the lower end of the latter thrust into a gel of agar containing potassium chloride, with which the calomel—or other reference electrode also makes contact. The e.m.f. of the combination is then measured in the usual way.

For experiments with the deuterium oxide (" heavy water "), a semi-micro cell was developed by La Mer and Armbruster.[9] It was adapted from the larger

2 H. J. S. Sand, *op. cit.*, Vol. 1, p. 27; S. Glasstone, *op. cit.*, p. 189; I. M. Kolthoff and H. A. Laitinen, " pH and Electro Titrations," New York, 1941, p. 88.

3 H. C. Lockwood, *J.S.C.I.*, 1935, **54**, 295.

4 H. A. Frediani, *Ind. Eng. Chem.*, Anal. Ed., 1939, **11**, 53.

5 V. A. Dorfmann, *Protoplasma*, 1936, **25**, 465.

6 J. Löbering, *Z. Anal. Chem.*, 1935, **103**, 180.

7 E. Biilmann, *Ann. Chim.*, 1921, **15** (9), 109.

8 T. Mikawa, *Biochem. J.*, 1933, **27**, 1829.

version designed by Harned and Wright,[10] and is suitable for volumes of from 2 to 4 ml.; the cell was subsequently modified as shown in Fig. 4A by La Mer and Rule.[11] In the precision experiments carried out by La Mer and his co-workers,[9, 11, 12] dissolved oxygen had to be removed from the solution by evacuating the system and, to prevent errors due to the entry of the test solution into the silver—silver chloride reference electrodes, frequent rinsing of this portion of the assembly was necessary. The system of stopcocks enables this to be done without interfering with the

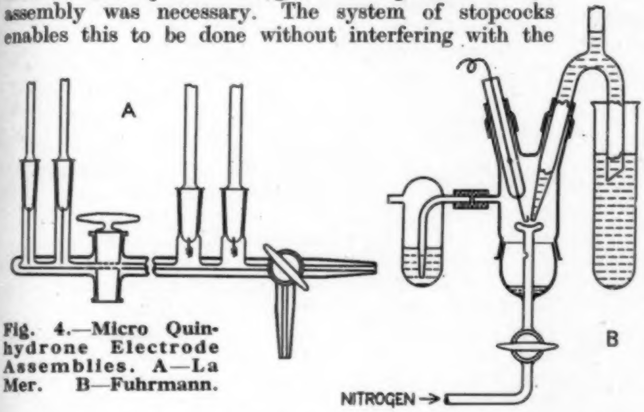


Fig. 4.—Micro Quinhydrone Electrode Assemblies. A—La Mer. B—Fuhrmann.

portion containing the deuterium oxide solution. It was found[9] that the results were as accurate as those carried out on the macro scale, and that equilibrium was attained within 30 minutes, when the e.m.f. remained constant to within 0·05 mv. for periods of from 2 to 4 hours. Using spiral platinum electrodes, the results were more reproducible than those obtained with large foil-type electrodes.

A thorough study of the application of the quinhydrone electrode to micro-pH measurements was made by Fuhrmann.[13] The cell designed by this worker is depicted in Fig. 4B, and permits measurements to be made with a sample having a volume of only a few tenths of a millilitre. The sample is placed upon the concave extremity of the vertical tube rising from the base of the apparatus. A small hole blown in the wall of this tube allows nitrogen to be passed through the cell in order to keep out oxygen. A gold-plated platinum wire-type electrode is used, and may be coated with quinhydrone before inserting into the cell in such a position that it does not touch the drop of test solution. After the oxygen has been displaced, the electrode tip is thrust down into the sample, thus introducing quinhydrone.

Fluids which are rapidly affected by the atmosphere are not easy to handle with ordinary technique. Problems of this kind frequently occur in biological work. An electrode device which allows measurement of pH to be carried out in complete absence of air is shown in Fig. 5. Further, the small sample may be collected under sterile conditions.[14] The "electrode vessel" is a 10-cm. length of 0·33 mm. bore quartz capillary. The electrode, which is inserted only when it is desired to perform the measurement, is a length of 36-g. platinum-iridium wire. The capillary may be sterilised by an alcohol flame immediately before use. One end is then dipped into sterile oil, so that a 5-mm. column of the latter is picked up. The end is then thrust into the slip of the needle making the puncture, when the issuing fluid follows the oil up the capillary. When a 1-cm. length has entered, the capillary is withdrawn and thrust through a previously prepared disc of agar-potassium chloride gel, thus isolating the sample from the air and allowing the capillary to be carried in an upright position. The tip of the platinum-iridium wire is then dipped into a sludge of quinhydrone and acetone, and, after the solvent has evaporated, is pushed down the bore of the capillary through the oil layer until it is about half way into the column of fluid. To prevent disturbance, the wire is then bent back and secured by plasticine or de Khotinsky cement, as shown. The agar-potassium chloride plug at the lower end of the capillary permits connection to be made with the reference electrode in the usual way. Besides its utility in direct sampling, the device may be used for withdrawing and examining portions of liquid stored beneath oil.

Of the various other micro-quinhydrone electrodes, mention may be made of those due to Krantz and his co-workers,[15] to Vodret,[16] and to Itano.[17] The electrode designed by the last-named was developed for work in connection with the examination of soils, and may be taken apart for cleaning. Itano's paper also includes a description of an ingenious portable calomel reference electrode.

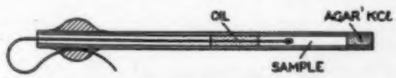


Fig. 5.—Micro Quinhydrone Electrode for working in absence of air.

In addition to the apparatus described here, the glass electrode has found extensive application. The principles governing it, and representative examples, will be discussed in the second part of this article.

(*To be continued.*)

9 V. K. La Mer and M. H. Armbruster, *J. Amer. Chem. Soc.*, 1935, **57**, 1510.
10 H. S. Harned and D. D. Wright, *J. Amer. Chem. Soc.*, 1933, **55**, 4851.
11 C. K. Rule and V. K. La Mer, *J. Amer. Chem. Soc.*, 1938, **60**, 1974.
12 S. Korman and V. K. La Mer, *J. Amer. Chem. Soc.*, 1936, **58**, 1396.
13 F. Fuhrmann, *Mikrochemie, Molisch Festschrift*, 1936, 130.

14 J. A. Pierce, *J. Biol. Chem.*, 1937, **117**, 651.
15 J. C. Krans, Jr., C. J. Carr and R. Musser, *Science*, 1937, **85**, 127.
16 F. L. Vodret, Rand. seminario Facolta sci. univ. Cagliari, 1933, **3**, No. 2, 55; *Chimie & Industrie*, **31**, 1339.
17 A. Itano, Comptes Rendus des travaux du Laboratoire Carlsberg, serie chimique, 1938, **22**, 235; Ber. Ohara Inst., landw. Forsch. Japan, 1938, **8**, 181.

Welsh Products Fair

THE Welsh Industries Fair, which was an annual event in pre-war years, is once again being held in Cardiff, from May 27 to June 1, 1946. Organised by the National Industrial Development Council of Wales and Monmouthshire, the Fair will be entirely restricted to manufacturers of the area, and enquiries for space already indicate that it will be the most representative exhibition of Welsh products ever staged.

Already the need for a large exhibition hall for South Wales has been demonstrated, as owing to the limited space available, exhibits have had to be scaled down, in order that as many firms as possible wishing to participate may be accommodated with stands.

Since the last Fair was held, numerous new light industries have been established in Wales, and these, together with the older basic industries, will provide many new and interesting features.

The Microchemistry Group

TWO papers of interest to microchemists were read and discussed at a meeting of the Microchemistry Group of the Society of Public Analysts, held in the Imperial College, South Kensington, on Friday, January 25. In the first, "Chemical Microscopy in Metallurgical Analysis," Miss I. H. Hadfield dealt with the identification of small amounts of metals by the formation of compounds of recognisable crystalline forms. Miss Hadfield pointed out that the technique of chemical microscopy is readily acquired. While spot tests deal essentially with the formation of coloured compounds, chemical microscopy, although in some cases benefiting from the formation of colour, is concerned with the appearance under the microscope of crystalline compounds.

The conditions required for successful chemical microscopy were outlined. The compounds formed should be fairly insoluble (if they are very insoluble, easily recognisable crystals are not produced), and the concentration of the constituent to be detected should be low.

Slides portraying the distinctive crystals obtained in selected reactions were shown. In some cases (*e.g.*, lead iodide, cobalt compounds, silver chromate) the colours help identification. In others (*e.g.*, silver chromate) pleochroism is developed. Mainly, however, identification is based on very distinctive shapes of the crystals and their aggregates. Some reagents form double salts of recognisable crystalline forms with a number of metals. Caesium chloride can be used to identify tin, antimony, bismuth and cadmium; and potassium mercuric thiocyanate for zinc, cadmium, lead, cobalt, copper and ferric iron. The presence of other metals, and of mineral acids, often modifies the shape of the crystals, in some cases with benefit to their identification.

The technique of chemical microscopy was described. In tests for individual metals a drop 2 mm. in diameter on a microscope slide (containing about $\frac{1}{1000}$ ml.) is sufficient. Best results are generally obtained with concentrations of less than 1%.

If the crystals sought for are relatively insoluble, the reagent is added in solution by placing a drop of the reagent solution close to the test drop, and drawing a channel with a fine glass rod from the reagent to the test drop, thus allowing the former to diffuse into the latter. The best crystals are generally found in the test drop at the ends of the line of contact between the reagent and test solutions.

If the crystals are relatively soluble, the addition of a tiny crystal of solid reagent was advocated. A variation in concentration of reagent is thereby achieved, and the optimum conditions for the growth of crystals obtained at some point in the drop. In addition, this method provides means of identifying crystals (such as lead iodide) which subsequently dissolve in excess of reagent.

If there is a tendency to super-saturation, the test drop is evaporated to dryness on the slide, and a streak of reagent drawn across it, thus providing nuclei for the growth of the crystals. This method is of advantage in the detection of sodium with a uranyl acetate solution.

A warning against the too literal interpretation of sensitivity figures, which had more basis in spot testing than in chemical microscopy, was given. They vary with conditions, and are of use principally for comparison.

Miss Hadfield detailed the relative advantages of separations performed on a watch glass or microscope slide and in a centrifuge tube. The latter provides a quick and clean method of segregating a precipitate without loss, and relative amounts of constituents can be readily estimated. But work on a watch glass can be followed at all stages under the microscope, an advantage which is of especial importance when opening up a sample, where it can lead to valuable information as to the presence of a mixture. The use of a hot-plate heated at one end only, thereby giving a graduation of temperature, was advocated for evaporation from a watch glass or slide.

The various methods of filtering, following in the main the practices of spot analysis, were described. Mention was made of the many uses of a hypodermic syringe connected to a glass tube drawn out to a capillary. It is valuable for the transference of liquid, for extraction with an organic solvent, for stirring by a stream of air bubbles, and for the addition of gaseous reagents such as hydrogen sulphide (which otherwise presents difficulty owing to the high pressures required to force the gas through a fine capillary). It gives much easier control than the use of a rubber teat. The use of an acetone solution of hydrogen sulphide was also mentioned.

Miss Hadfield gave a brief outline of the complete analysis of a metal sample, involving the minimum of transference. It involved successive treatments with nitric, hydrochloric and sulphuric acids, followed by individual tests for the metals thus separated.

In the discussion which followed the use of photographs of crystals for comparison purposes was advocated. The difficulties in the simultaneous detection of cadmium and zinc were discussed, and the value of crystal tests for the rare metals mentioned.

Miss Hadfield exhibited many specimens of apparatus used for the manipulation of small amounts of material.

Dr. W. A. Kirkby then gave "A Review of Methods of Microanalysis of Gases." This consisted of a summary of the development of methods with special attention to the improvements in design of apparatus, which had taken place during the last thirty years. Dr. Kirkby pointed out the need for the development of a suitable technique for handling volumes of gases of about $\frac{1}{2}$ ml. or $\frac{1}{10}$ ml.—between the micro- and macro-quantities.

Dr. Kirkby dealt in most detail with variable volume methods, which in the last 15 years have been more widely used than those based on the variation of pressure. He traced the improvements in the design of apparatus, mentioning the replacement of glass-in-rubber pistons for the movement of the confined gas bubble by micrometer screw methods, and the constant endeavours to reduce to a minimum, and to improve operations involving the transfer of the gas bubble from the measuring apparatus to the absorption apparatus. Amongst the more promising of modern methods which were described is that based on the use of dry gas and dry absorbents, since it eliminates the errors due to aqueous vapour content, and to the absorption by reagents of other than the intended gases. There is, however, the disadvantage that the dry mercury tends to adhere to the walls of the containing vessel.

Mention was also made of physical methods based on spectroscopic analysis, measurements of thermal conductivity, and of dielectric constant, and Dr. Kirkby gave a brief account of the reagents used for the absorption of oxygen, hydrogen, carbon monoxide and hydrocarbons.

METALLURGICAL DIGEST

Subzero Treatment of Molybdenum-Tungsten High Speed Steel

By R. G. Kennedy

THE effect of cooling to subzero temperatures on hardened molybdenum-tungsten high-speed steel has been studied by means of dilation, specific volume, hardness, static torsion and mutual indentation hardness tests at elevated temperatures, and by metallographic examination and tool performance tests. The effect on physical properties of such factors as the subzero temperature reached, the time of holding at such temperature, and the time of ageing a room temperature before subzero cooling have also been studied. The effect of subzero cooling before and after tempering has been examined in conjunction with the usual heat treatment variables of hardening temperature, tempering temperature and the quenching temperature attained before tempering.

The tests were carried out on various molybdenum - tungsten high - speed steels containing 0·74–0·81% carbon, 3·68–3·97% chromium, 1·40–1·73% tungsten, 8·24–9·2% molybdenum and 1·0% vanadium. Static torsion, transverse bend and dilatometer test specimens were made from $\frac{5}{16}$ in. dia. ground rod, and hardness and specific volume measurements were made on the torsion test specimens. Specimens for measuring hot hardness consisted of small cylinders which were accurately ground after heat-treatment to a diameter of 0·3937 in. and to a similar length. Tensile tests were made from $1\frac{1}{16}$ in. dia. rod and the various drills used in the drilling tests from stock varying from $\frac{9}{32}$–$\frac{1}{16}$1 in.

Heat treatment of all types of test specimens and tools were carried out at 1,095°–1,225° C., except the dilatometer specimens which were specially hardened at 1,205° C. Quenching was done in oil, salt, air or a lead-tin bath. Where subzero cooling was interposed in the heat-treating cycle, continuous cooling from the quench bath temperature or the tempering temperature, through room temperature to the subzero temperature was used. Temperatures down to −84° C. were obtained in a commercial chilling unit of the cascade type, while liquid nitrogen was used for temperatures of − 190° C.

Tensile, torsion, and transverse bend tests were made with specimens from the same heat of high-speed steel in order to furnish correlation factors with which the static torsion test results of the present investigation might be compared with the results of tensile and transverse bend tests previously published for various types of high-speed steels. Tool performance tests in which all variables were controlled as closely as possible were carried out with ordinary hardening compared to various types of subzero hardening. Some of the results obtained from the various tests are given in Tables I and II.

The results obtained from the various tests showed that continuous cooling from a hardening temperature of 1,205° C. resulted in the subzero transformation of at least 95% of the austenite which would transform, if cooled to a temperature as low as − 190° C. The formation of additional martensite during subzero cooling after hardening (no subsequent tempering) gave an increase of specific volume, hardness and strength, as compared with normal hardening. The increment of hardness and strength gained by subzero hardening was maintained up to a tempering temperature of at least 425° C., but at 560° C. it disappeared. Subzero hardening followed by tempering 1 hr. at 560° C., produced a decrease in plasticity as compared with normal hardening.

From *Trans. Amer. Soc. for Metals*, 1945, Vol. 34, pp. 250–292.

TABLE I

EFFECT OF HOT QUENCHING AT 600° C. WITH SUBZERO COOLING INTERPOSED

(*a*) Before Single Tempering at 560° C.; (*b*) Before and also During a Multiple-Tempering Cycle at 540° C., and (*c*) before and During Multiple Cycles at 560° C.

Treatment	Rockwell Hardness C. Scale	Modulus of Rupture Lbs./sq. in.	Torsional Modulus of Elasticity	Proportional Limit Lbs./sq. in.	Plastic Strain In per. in.	Specific Volume C.c./Grm.
Normal Practice: Austenitised at 1,200° C., quenched to 540° C., air cooled to room temperature, tempered at 560° C. for 1 hr.	65·8	342,000	10,200,000	160,000	0·037	0·12656
Austenitised at 1,200° C. Salt bath quenched at 600° C., held 10 mins., air cooled to 82° C., continuously cooled to −86° C., held 2 hrs., and subsequently— (*a*) Not tempered	67·1	234,500	9,900,000	120,000	0·005	0·12652
(*b*) Tempered at 560° C. for 1 hr.	64·2	325,000	10,300,000	180,000	0·033	0·12662
Tempered at 540° C. for 3 hrs. Continuously cooled to −86° C., held 2 hrs., tempered at 540° C. for 3 hrs.	64·4	325,000	10,500,000	210,000	0·025	0·12650
Tempered at 560° C. for 30 mins. Continuously cooled to −86° C., held 2 hrs., retempered at 560° C. for 30 min.	64·0	322,000	10,500,000	140,000	0·038	—
Tempered at 560° C. for 1 hr. Continuously cooled to − 86° C., held 2 hrs., retempered at 560° C. for 1 hr.	64·0	322,000	10,500,000	170,000	0·028	—

TABLE II. SUMMARISED TOOL TESTS.

Group	Treatment and Description	Performance 1: Percentage Weighted According to Number of Grinds	Performance 2: Total Number of Grinds	Average Performance 1 ÷ 2 %
I	Subzero Cooling interposed in Heat Treating Cycle before Single Tempering	18,866	189	100
II	Subzero Cooling interposed in Heat Treating Cycle after Single Tempering	17,869	163	110
III	Subzero Cooling interposed in Heat Treating Cycle between Multiple Tempering	21,263	223	95
IV	Multiple Subzero Cooling interposed in Heat Treating Cycle before and after Single Tempering	7,786	76	102
V	Multiple Subzero Cooling interposed in Heat Treating Cycle before, after, or between Multiple Tempering	24,952	243	103
VI	Standard, no Subzero Cooling	18,400	184	100

Subzero cooling after tempering 1 hr. at 560° C., produced little change in hardening, strength or plasticity when hardening temperatures of 1,205° C. or higher were used. At lower hardening temperatures subzero cooling after tempering yielded some increases in hardness and strength, and a marked increase in plasticity. Subzero cooling before or after tempering in conjunction with hot quenching at 595° C. or 560° C. produced no significant change in hardness, strength or plasticity. No significant change in the mutual indentation hardness at elevated temperatures was produced by subzero cooling before or after tempering at 560° C. There was also no significant effect produced on the appearance of the micro-structures by subzero cooling to − 84° C. before or after tempering at 560° C.

Subzero cooling before tempering at 560° C. gave tool performance results, Table II, equal to those obtained with normal heat-treatment and slightly inferior to those obtained by subzero cooling after tempering at 560° C.

Sintered Beryllium for X-ray Tube Windows

By Floyd C. Kelley

BERYLLIUM is well suited as a transparent material for X-rays, or windows for X-ray tubes giving soft rays.

It has been used in the vacuum-cast condition for X-ray windows, but its large-grain structure has given trouble. When the windows are brazed to a suitable metal for sealing to glass, the stresses set up result in slippage along the cleavage planes. This movement is often sufficient to cause fracture of the crystal or chipping of the grain, resulting in leakage or failure of the seal.

It has been found that material with a much finer grain structure can be produced from coarse beryllium powder by pressing and sintering without the use of a grain-refining element such as titanium. The windows are stronger, less fragile and less susceptible to cracking due to stress. The material is much more ductile than that produced by melting, and can be readily hot worked, ground to thickness and silver soldered to a suitable material. It also has a greater transparency to X-rays than titanium-beryllium alloy.

From *Iron Age*, 1945, 68-69.

The production of beryllium sheet for transparent X-ray windows was accomplished by starting with an ingot of pure, vacuum-melted metal. The ingot was converted into chips by machining without the use of a coolant. These turnings were ground in a mortar until they passed a 60-mesh screen. Twenty-five grams of the coarse powder were then pressed in a cylindrical mould to form a compact about $\frac{5}{8}$ in. thick by $1\frac{1}{2}$ in. dia. using a pressure of about 40 tons/sq. in. The pressure was transmitted to the compact by plungers acting from the top as well as the bottom.

The pressed compacts were sintered in a closed iron tube in a hydrogen furnace at 1,235° C. for 3 hrs. At the end of 3 hrs. the charge was withdrawn into the cooling chamber. There was considerable shrinkage of the compacts which was difficult to determine accurately. The density varied from about 1·75–1·85.

Finer powders were tried, but there seemed to be little advantage in using them. The shrinkage was greater, but the final density was about the same.

After sintering, the compact was machined to a uniform size, and placed in a high-speed steel container machined to take the compact. A cover was also riveted to the container to permit hot rolling. The container with the compact was heated in a hydrogen furnace to 800° C., and then hot rolled from 0·530 in. to various degrees of thickness, depending upon that desired by reheating after each rolling operation.

The average grain size in the sintered compact ran a little over 0·1 mm. in dia., but in a fused ingot of the same mass there might be only two or three grains. After hot rolling and subsequent annealing at 875° C. for 7 min., the average grain diameter did not exceed 2–3 mils.

It was found that windows could be silver soldered very satisfactorily with pure silver or eutectic silver solder in pure dry hydrogen without a flux or in line hydrogen by the aid of a flux.

Windows lapped to 0·010 in. thickness were found to be vacuum tight after silver soldering.

Thorium

IN 1828 Pastor Jens Esmarck discovered a new mineral on the Island of Lovo, Norway, and sent a sample to J. J. Berzelius, who established the presence of a new metal in the mineral which he named thorium after the ancient Scandinavian god Thor. But samples of the new mineral (orangite) and the thorium salts derived from it remained museum curiosities for the next 52 years. Then (1880) the Austrian chemist, Baron Auer von Welsbach, started his classical researches on surface combustion which culminated in the famous Welsbach gas mantle. This mantle gave gas-lighting a tremendous boost, increasing its efficiency ten-fold. The carbon incandescent electric lamp was confronted with serious competition. Extensive deposits of thorium mineral (monazite) were discovered in Brazil and elsewhere, and for 15 years or more the mantle industry flourished. In 1910 the ductile tungsten incan-

From *Bulb. Electrochem. Soc.*, July, 1945, 2.

[1] J. W. Marden, Trans. Electrochem. Soc., 1934, 66, 39.

descent lamp was marketed and soon displaced the mantle.

The radioactivity of thorium was discovered in 1898 by Mme. Curie and Professor G. C. Schmidt. Thorium is the parent substance of an entire series of radioactive elements. The presence of about 0·7% thorium in many of the tungsten filaments may be readily detected by the blackening of a photographic plate due to the radioactivity of the thorium atom. Thorium metal crystals are face-centred cubes. Thorium is very ductile, much like lead. The presence of small quantities of oxygen in the metal does not render the metal brittle. (This is not so in the case of titanium.)

There are two practical methods for the production of thorium metal: (1) the calcium, calcium chloride reduction in an air-tight steel bomb; (2) the electrolysis of fused sodium chloride plus potassium chloride together with the double potassium thorium fluoride. In the fused salt-bath method a black thorium metal powder adheres loosely to the molybdenum cathode. Marden[1] records 1,845° C. as the melting point of Thorium metal, and 11·3 as its density. He discusses three principal uses for thorium metal: photo-electric cells, glow-tube electrodes, and X-ray targets. The X-ray efficiency of thorium is 120, as compared with 91 for tungsten.

Thorium oxide is a well-established catalyst in hydrogenation reactions and in the synthesis of liquid hydrocarbons from carbon monoxide and hydrogen.

Grain Growth and Refinement of Magnesium Alloys

A Composite

IT is a well-known fact that magnesium-alloy castings are apt to be coarse-grained, if the melt is not superheated several hundred degrees above the melting point before casting. As little definite information is available regarding the effect of temperature and time of superheat on the final grain size, an investigation was recently carried out by R. Hultgren, D. W. Mitchell and B. York,[1] on the grain refinement of a carbothermic magnesium alloy by superheating. The magnesium alloy studied was a sand casting alloy with a nominal composition of 9% aluminium, 2% zinc, 0·1% (min.) manganese, and the balance magnesium, prepared from magnesium produced by the carbothermic process. Five lb. of the magnesium alloy ingot and 2–3 lb. of carbothermic magnesium were melted, fluxed at 704°–732° C., and cooled to 677° C. A small portion of the melt was then heated to just below the desired superheat temperature, and then held for a definite time at the superheat temperature, after which it was cooled slowly to slightly above the casting temperature, and then cast into cast-iron moulds heated to 182° C.

Grain-size measurements were made after full solution heat-treatment, and the effect of time and temperature of superheat and also of other variables on grain size determined. The results obtained from the experiments showed a carbothermic magnesium alloy to experience full grain refinement at temperature as low as 760° C.—temperatures considerably lower than for alloys prepared from electrolytic magnesium. When held at 704° C. or 732° C., the unsuperheated alloy experienced incomplete grain refinement, while the superheated alloy coarsened to some extent. The grain size obtained was virtually independent of superheat temperature provided sufficient time of superheating was allowed, and the time required was 1 hr. at 760° C., and much less at higher temperatures.

Other processes for securing grain refinement at low temperatures have also been investigated by R. Hultgren and D. W. Mitchell.[2] The alloys studied were the common sand-casting magnesium alloys containing approximately 9% aluminium, 2% zinc, 0·1% (min.) manganese, and 5·5% aluminium, 2·5% zinc, 0·1% (min.) manganese, respectively. After melting, fluxing and cooling to 677° C., a portion of the melt was heated to the temperature to be investigated, and four portions given a different treatment. In a typical case, one portion was stirred vigorously for 5 min., acetylene gas was passed through a second portion for 5 min., a third portion was superheated to 870° C. for 15 min., then cooled to casting temperature, and the fourth was held at the temperature of stirring or gassing without other treatment. Each portion was then cast into three "nonturbulent" moulds of identical shape.

The results obtained from these investigations showed that grain refinement of the two alloys could be obtained without superheating, if they were stirred vigorously at 750° C., and that electrolytic and carbothermic magnesium both experienced full grain refinement on stirring. Increasing the temperature of stirring above 750° C. did not increase the degree of refinement, while at lower temperatures the degree of refinement decreased. Stirring in a graphite crucible with a graphite rod gave the same grain refinement as stirring in an iron crucible with an iron rod. Bubbling of acetylene or natural gas refined the grain of both alloys.

A report has also been made of an investigation by C. H. Mahoney, A. L. Tarr and P. E. Le Grand[3] of inherent grain size of magnesium alloys as related to casting temperatures from above the melting range through superheating temperatures, and of a method for obtaining fine-grained alloys without superheating.

TABLE I. TYPICAL COMPOSITION OF ALLOYS.

No.	Composition		
	Al	Zn	Mn
A5	3·5– 5·0	0·2–0·5	0·15–0·4
A8	7·6– 8·5	0·2–0·6	0·2 –0·5
17	8·5– 9·5	1·7–2·3	0·13 min.
4	5·5– 6·5	2·7–3·3	0·18–0·5
2	9·4–10·6	—	0·13 min.
Az91	9·5–10·5	0·2–0·6	0·2–0·5

Approximate compositions of the alloys tested are given in Table I. Test castings for grain-size determinations were obtained by casting into steel moulds heated to 200° C. Special treatments given to the alloys included the bubbling through the molten metal of various gases, including air, carbon dioxide, propane, flue gas, oxygen, nitrogen and ammonia, and the addition of solid carbon-containing materials such as magnesium carbonate, peat, coal, graphite, coke, lampblack and pitch. Two groups of tests were carried out, the first to determine the charac-

1 *Metals Technology*, 1945, vol. 12, No. 4, A.I.M.M.E. Technical Publication No. 1853, pp. 1-8.

2 *Metals Technology*, 1945, vol. 12, No. 4, A.I.M.M.E. Technical Publication No. 1854, pp. 1-5.

3 *Metals Technology*, 1945, vol. 12, No. 4, A.I.M.M.E. Technical Publication No. 1892, pp. 1-20.

teristic grain size at various temperatures on cycles of heating, superheating and cooling to just above the freezing point, and the second on carbon-inoculated melts.

The results of the various tests showed that castings from non-superheated metal had grain sizes with regularly-increasing coarseness with increase in temperature from 650°–800° C., while between 800° and 900° C. castings showed progressively-increasing grain refinement effects typical of superheating. Castings from superheated melts between 900° and 650° C. indicated a gradual but limited loss of grain refinement. Grain-refinement effect at 900° C. increased with increasing aluminium content, or total aluminium and zinc content, while carbon-treated melts, even though the melts had not been heated higher than 800° C., showed as fine a grain structure as castings from superheated melts.

The mechanical properties of sand-cast magnesium alloys containing aluminium, treated by carbon, and not superheated in the as-cast, solution-treated and aged conditions, were as satisfactory and more consistent than the best properties of the corresponding alloys that had been given the regular superheating treatment. It was also found that when melts of the alloys investigated were super heated, cooled and solidified, and then remelted the grain-refining effect of superheating was substantially lost, and superheating or carbon inoculation was necessary for complete recovery of grain refinement. In alloys superheated, cooled to just above the freezing zones, but not solidified, the finest grain sizes could only be obtained by resuperheating or carbon inoculation.

Factors affecting abnormal grain growth in magnesium alloy castings have been studied by A. T. Peters, R. S. Busk and H. E. Elliott, who discuss techniques developed in solving production problems, the mechanism by which coarse-grain growth occurs, and the fundamental conditions that produce such an effect. Experimental work included the thermal history of the mould; the effect of alloy composition, of chilling and stressing, and of heat-treatment on germination; and the metallographic study of germination. Results obtained showed that cast magnesium alloys of certain composition ranges and under certain casting conditions displayed the unusual property of undergoing local grain growth during heat treatment without the necessity of intentional mechanical stressing. Germination occurred only in certain composition ranges in magnesium-alloy castings, and only when a fine as-cast grain size was obtained by superheating and chilling, and control methods have been developed for suppressing germination. Metallographic studies showed that germination occurred during heat-treatment by a general recrystallisation of the as-cast structure, followed by the early coalescence of grains at a few spots throughout the casting, and by growth of the grains so formed.

4 *Metals Technology*, 1945, vol. 12, No. 4, A.I.M.M.E. Technical Publication No. 1864, pp. 1-23.

Avoiding Black Film on Etched Aluminium

FLUORIDE preparations are frequently used as etchants for aluminium sheets prior to spot welding, but, in many cases, after removing the oxide, they leave a black film on the surface of the etched metal. Cleaning off this film is an extra operation which adds to the time and cost of processing. It has been demonstrated that deposition of this film can be prevented by taking advantage of a well-known principle of electrochemistry involving the electromotive series of metals.

The etchant normally used is a water solution of an acid radical containing fluorine atoms which react similarly to those in hydrofluoric acid, but at a greatly-reduced rate. The fluoride preparations etch the aluminium surface forming metallic fluorides and liberating hydrogen. Since commercial aluminium alloys may contain iron, manganese and copper, in addition to other metals and non-metals, these are also attacked and enter the solution. The aluminium tends to replace the less reactive metals in the electromotive series. These are deposited on the aluminium parts as metallic salts, which have a high electrical resistance.

If the alloying metals are removed from the solution as they are dissolved, they will not deposit on the etched surface. This removal can be accomplished by the use of a metallic couple composed of aluminium in the form of scrap, and a metal less reactive than any of the alloying metals, such as lead, which is quite low in the electromotive series. The aluminium scrap will go into solution, replacing the less reactive metals which will deposit upon the lead in a non-conducting layer. For this reason, it is advisable to have as large a lead surface as possible—a goal which is more easily attained by using a lead-lined tank. The couple can be set up by simply dropping some flat pieces of aluminium scrap in the bottom of the tank.

When the lead lining of the tank has been well-coated with a black film, the solution should be drained out and the film washed off. The lead is not affected by the etchant. Although the etchant can be replenished and brought up to its original strength, it is more economical to make up a new solution as the fluoride preparations are relatively inexpensive. Thus, the cost of preventing the formation of the black film on the workpiece is negligible and is more than offset by increased efficiency in the actual spot-welding operation.

From *Iron Age*, 1945, 156, 57.

Failures in Rammed Carbon Blast-Furnace Lining

By R. Klesper

DISCUSSING failures of blast-furnace refractory linings and the ramming of carbon aggregates, one failure is cited which was discovered on drilling the shell plate around a carbon-lined hearth which had been in operation for two years. A space about $1\frac{1}{2}$–$2\frac{1}{2}$ in. wide was found between the back of the rammed lining and the plate, and the lining itself had vertical cracks in it which were full of loose powder. It is probable, Klesper suggests, that starting the furnace too quickly was the initial cause of this failure. The correct preheating of the mix is very important because if it is made too hot, the heavier hydrocarbons in the tar are cracked, and its binding properties are destroyed. Crushed coke mixed with tar should be prepared for ramming by heating to 212° F. on an iron plate heated with steam or by a coke-oven gas flame.

Tests were made by building up blocks from layers of ramming material with and without a coating of tar

From *Stahl und Eisen*, 1944, 64, 774-781.

between the layers. After curing, the tar coating became a thin porous layer of loose carbon powder, while the blocks made without tar coatings were hard and homogeneous throughout. Roughening of the top of one layer before applying the next layer, even after 24 hours' ageing, was quite sufficient to insure complete fusion of the joint during curing.

Since the requirements for the protective brickwork in the case of a rammed-carbon hearth are much more exacting than for a hearth made of carbon blocks, the wall in the former case should be at least 10 in. thick.

Gray Iron for High Temperature Uses

By C. O. Burgess and T. E. Barlow

CODES limiting the use of cast iron to temperatures of 450° F. (230° C). were established approximately 31 years ago, before modern cast irons of controlled structure and composition were in common use. Despite this limitation, cast irons of controlled analysis have been developed which can be successfully employed in numerous engineering applications within a temperature range of 450 to 1,000° F. (230 to 540° C.). In a survey of 99 concerns and 108 individuals made under authorization of the U.S. War Metallurgy committee, data were obtained on 223 applications of cast iron at temperatures of over 230° C. and pressures up to 2,000/in.[2] The industries surveyed were the steam and internal combustion engine industries, furnace and power industries, petroleum, paper, chemical metallurgical industries. All irons were classified with respect to carbon and carbon equivalents [% C + 0·3 (% Si + % P)], alloys, ladle inoculation and tensile strength. A definite tendency has been shown to hold the total carbon content within 2·7 to 3·35% and the carbon equivalent in the range of 3·4 to 3·9%. Unalloyed irons of a carbon equivalent of 4·0% or above are normally not suited for high temperature pressure or steam applications. About 34% of the irons are of the low-alloy type, having received small additions of one or more of the elements chromium, nickel, copper, molybdenum and vanadium. The number of alloyed irons increases with severity of temperature conditions, and chromium is the most common alloying element. Ladle inoculation is widely employed in irons used for high-temperature applications, and it is evident that for successful heat resistance it is advisable to hold the tensile strength of cast irons to a minimum of 35,000/in.[2] with an average strength of about 40,000/in.[2].

Unpublished research shows that cast irons (up to 3·9% equivalent carbon) can resist loads of approximately 10,000/in[2]. at 400° C. without exceeding a creep rate of 1% in 10,000 hr. Further free ferrite seriously lowers the ability of an iron to resist growth, and the use of small amounts of alloying elements to stabilise the pearlite are recommended.

On the basis of the factual survey the present arbitrary limiting temperature of 230° C set by the A.S.M.E. Boiler Code and other code bodies for all cast irons irrespective of type does not appear justified. It is recommended that any cast iron intended for high-temperature applications be required to meet definite specifications. The suggested specifications include: (1) Establishing a minimum tensile strength for irons to be used within certain temperature ranges; (2) establishing a preferred chemical analysis with the purpose of controlling carbon equivalent; and (3) establishing foundry requirements covering minimum percentage of steel to be used in the furnace charge, additions of special alloys, and the use of ladle inoculation.

From *American Foundryman*, May, 1945.

Annealing of Cold-Rolled Iron and Iron Binary Alloy

By C. R. Austin, L. A. Luini and R. W. Lindsay

THE mechanism of strain hardening in metals and alloys, and the removal of strain hardening by annealing involves a number of factors including the prior history and original structure of the material involved, the type and amount of deformation to which it has been subjected, the time and temperature of annealing and the chemical composition of the material. These factors have been investigated in pure iron, but data is lacking regarding the effect of second element additions on strain-hardening characteristics and response to annealing. The present investigation was therefore carried out to determine the strain-hardening characteristics of unalloyed iron and its subsequent softening during annealing and to ascertain the effect upon these processes of a second element in solid solution in the iron.

From Trans. Amer. Soc. for Metals, 1945, vol. 35, pp. 446-480.

The compositions of the pure iron and alloys investigated are given in Table I. The alloys as received in the form of bars $\frac{5}{16}$ in. diameter were cold-rolled to a thickness of 0·223 in., and subjected to a softening annealing consisting of heating to 975° C. for 1 hour, furnace cooling to 650° C., holding for 20 hours and then furnace-cooling to room temperature. The softened alloys were given reductions in thickness of 5, 20, 40, 75 and 90% by flat cold-rolling, the thickness being reduced approximately 0·015 in. per pass. The progress of hardening

TABLE I.—CHEMICAL COMPOSITION OF ALLOYS INVESTIGATED.

Alloy	C	Cr	Ni	Mn	Mo	Co	Si
Pure Iron	0·02	0·003	0·032	0·03	0·004	0·005	0·003
Chromium	0·03 0·02 0·03	0·45 0·99 4·83	0·032 0·034 0·023	0·05 0·03 0·03	0·004 0·004 0·004	0·005 0·005 0·005	0·012 0·004 0·008
Nickel	0·03 0·02 0·02	0·003 0·003 0·003	0·57 1·15 4·83	0·03 0·03 0·03	0·004 0·004 0·004	0·005 0·005 0·005	0·004 0·004 0·004
Cobalt	0·02 0·02 0·02	0·003 0·003 0·003	0·037 0·043 0·08	0·03 0·05 0·03	0·004 0·004 0·004	0·52 1·00 5·08	0·004 0·004 0·004
Manganese	0·02 0·06	0·003 0·003	0·032 0·030	0·69 1·33	0·004 0·004	0·005 0·005	0·004 0·004
Molybdenum	0·03 0·03 0·04	0·003 0·003 0·002	0·054 0·023 0·016	0·03 0·03 0·03	0·11 0·54 1·50	0·005 0·005 0·005	0·004 0·004 0·004
Silicon	0·03 0·02 0·02	0·003 0·004 0·003	0·033 0·032 0·055	0·03 0·03 0·03	0·004 0·004 0·004	0·006 0·005 0·005	0·22 0·59 1·21

by cold-rolling was measured by means of the Vickers hardness test. Specimens of ½ in. length were cut from the various cold-worked conditions and annealed for 1 hour at temperatures ranging from 330°–870° C. The effect of time at temperature as a variable was studied by annealing specimens at 480° C. for various periods up to 20 hrs.

The results obtained on unalloyed iron were in agreement with other investigation upon the subject of cold-working and annealing of metals and alloys as regards the effect of amount of deformation and the process of recovery, grain growth and recrystallisation. It was found that softening at the lower temperatures occurred as a consequence of recovery. Annealing at high temperatures caused recrystallisation with all degrees of deformation except the 5% reduction which softened at all temperatures by recovery and showed marked grain growth at 870° C., possibly as a consequence of boundary migration without recrystallisation. As regards recrystallisation, the temperature of the beginning of recrystallisation was lowered as the degree of deformation was increased. Thus, recrystallisation was initiated at 540° C., with specimens reduced 20% in thickness, while with specimens reduced 90% in thickness the temperature was lowered to 425° C. Grain size immediately after recrystallisation was finer as the degree of deformation was increased and the growth of grains developed by recrystallisation was most pronounced with finely recrystallised grains.

The softening curves for the cold-worked binary alloys were quite similar in contour to those for unalloyed iron, but the softening temperature, defined as the mid-point between the as-worked hardness and the fully annealed hardness, was raised by certain of the alloying elements. Molybdenum was most potent in this respect, raising the temperature by as much as 205° C. in some instances. Chromium and manganese were also quite effective, while silicon was only mildly so. Cobalt and nickel had not any effect in comparison with the unalloyed iron. It was also noted that the softening temperature was raised most pronouncedly by the initial small addition of the alloying element and only slightly more so by larger additions.

The effect of time as a variable in the annealing process was studied at 480° C., at which temperature softening occurred very definitely and yet was not too rapid to be followed conveniently. It was found with unalloyed iron that softening occurred by recovery in specimens reduced 5 and 20% and by practically complete recrystallisation in specimens reduced 75 and 90%. Recrystallisation was only partially complete in the specimen reduced 40% and this specimen did not soften to the same extent as the others. In all cases, hardness decreased rapidly in the first hour and more slowly thereafter. With the binary alloys, molybdenum, manganese and chromium retarded softening at 480° C., as compared to unalloyed iron with molybdenum being the most effective. Silicon and cobalt caused a moderate decrease in rapidity of softening with severely deformed specimens, but exerted no effect with lower reductions. Nickel was relatively ineffective in all instances.

Metal Powders by Fused Salt Electrolysis

By W. J. Kroll

INCREASING interest in powder metallurgy has suggested the production of relatively pure metal powders or metal-alloy powders by the fused electrolyte method. The three major metal products of the fused electrolyte industry are sodium, aluminum and magnesium. In each case the temperature of the fused salt bath is decidedly above the melting point of the metal produced. Accordingly, all three metals are removed from the cells in liquid form. But when fused salt electrolyses are carried out at a temperature above the melting point of the electrolyte, but below that of the metal to be deposited at the cathode, we obtain, at high-cathode current densities, a deposit of metal dendrites, interspersed with electrolyte. This method has been used in the past with baths constituted of halides, borates, phosphates, etc., for production of thorium, uranium, tantalum, cobalt, nickel, iron, copper, zirconium, silver, platinum, beryllium, molybdenum, tungsten, chromium and aluminium. The advantages of this type of electrolysis are lower operating temperature and the resulting reduced power consumption ; the winning of metals far below their melting point ; and operating at relatively high current densities since the fine crystals covering the face of the cathode present a relatively large actual surface. Refining can be accomplished by using soluble anodes. The disadvantages are the difficulties encountered in removing the deposits from the cell, the elimination of the entrapped electrolyte, and the reaction of air and moisture with the bath.

In the typical case of refining iron by anodic dissolution in an alkali-chloride bath, carbon, sulphur, silicon and phosphorus are eliminated. The iron product obtained is very pure, soft and free of nitrogen and hydrogen. It is dense, sharp-edged, free-running and of grain size, suitable particularly for powder metallurgy.

From paper to meeting of the Electrochemical Society, Atlantic City, April, 1945. *Chemical and Metallurgical Engineering*, April, 1945.

Tin Deposits Discovered in Alaska

THE discovery of two tin-bearing veins in the bedrock of Cape Mountain, in the western part of Seward Peninsula, Alaska, was announced recently by the U.S. Geological Survey. Tin-bearing deposits were investigated in the Cape Mountain and Lost River areas by the Survey and the U.S. Bureau of Mines during 1943 and 1944. Field examinations of loose rock covering the hill slopes in the Cape Mountain area during 1943 resulted in the further exploration of three sites. Two of these were trenched by the Bureau of Mines during 1944, and exposed tin-bearing veins in the underlying bedrock. One vein 140 ft. (43 m.) long, and locally 14 in. (36 cm.) wide, is of a type from which the large pieces of nearly solid tin ore found in adjacent stream gravels could have been derived. Additional sites of tin ore float were found in the 1944 season. The ore bodies found thus far enhance the possibility of discovering more deposits. Tin ore is found in the Lost River area in dykes, veins, and in mineralised zones cutting the limestone near the dykes. Drill cores showed that the dikes carry little tin at depth. However, other cores revealed a fair tin content in the veins and mineralised area, as well as in the upper portion of a granite mass that lies several hundred feet below the surface in an area south of the dykes at Lost River. Drilling by the Bureau during 1944 was oriented to determine the extent of this mineralised portion of the granite. Trenching also led to the discovery of several small but rich veins.

From *Engineering and Mining Journal*, April, 1945.